University of Connecticut

Department of Economics Working Paper Series

Cost Improvements, Returns to Scale, and Cost Inefficiencies for Real Estate Investment Trusts

Stephen M. Miller
University of Connecticut and University of Nevada, Las Vegas

Thomas M. Springer
Clemson University

Working Paper 2007-05

February 2007

---

341 Mansfield Road, Unit 1063
Storrs, CT 06269–1063
Phone: (860) 486–3022
Fax: (860) 486–4463
http://www.econ.uconn.edu/

Abstract

This paper extends the existing research on real estate investment trust (REIT) operating efficiencies. We estimate stochastic-frontier, panel-data models specifying a translog cost function. The specified model updates the cost frontier with new information as it becomes available over time. The model can identify frontier cost improvements, returns to scale, and cost inefficiencies over time. The results disagree with most previous research in that we find no evidence of scale economies and some evidence of scale diseconomies. Moreover, we also generally find smaller inefficiencies than those shown by other REIT studies. Contrary to previous research, higher leverage associates with more efficiency.

Journal of Economic Literature Classification: G2, L25, L85

Keywords: Real Estate Investment Trusts, X-efficiency, scale economies

I. Introduction

This paper examines frontier cost (technological) improvements, scale economies, and operating efficiencies of publicly traded Real Estate Investment Trusts (REITs). The REIT industry experienced explosive growth over the last fifteen years from a total market capitalization of \$8.74 billion in 1990 to \$305.1 billion in 2004 (NAREIT.org). Viewed differently, the 119 REITs in 1990 averaged \$73.4 million assets whereas the 190 REITs in 2004 averaged \$1.6 billion in assets, a dazzling compound growth rate of 22.8 percent per year. As a consequence, considerable interest and analysis emerged on the underpinnings and sustainability of this sector's growth.

Two schools of thought offer conflicting opinions on the long-term viability of projected growth and consolidation in the REIT industry. One view argues that the real estate industry still exhibits a cyclical pattern and that the industry cannot long sustain the current growth spurt. For example, Vogel (1997) states that external factors drive the rapid growth of the REIT industry, not superior operating performance. The alternative perspective argues that the full potential for this sector remains significantly untapped and that REITs can continue to expand as low-cost producers of investment real estate. Linneman (1997) argues that the sources of the competitive advantage include economies of scale, lower capital costs, and superior sources of capital. Generally, most commentators think that scale economies and the potential for gains in operating efficiencies do exist. Considerable debate continues, however, as to the sources and the magnitude of these efficiencies (see Anderson, Lewis, Springer, 2000, for a general review).

The literature on REIT operating efficiencies has evolved mostly along the lines of improved estimation methods. Our analysis adds to the existing literature along a number of dimensions. First and foremost, we provide additional methodological improvements. Whereas previous studies generally use cross-sectional analysis, we use a panel-data model. Specifying a translog cost function and using 1995 to 2003 data, we estimate a stochastic-frontier panel-data model of REIT operating efficiencies that also identifies various factors that influence efficiency. The methodology allows for different production plans or technology to exert control over the stochastic frontier estimation as the analysis moves forward from one year to the next. That is, the stochastic frontier and its implied technology base get updated over time as more information becomes available.[1] Also, we use two alternative output measures, total assets and revenues, and we incorporate input costs into the model. Most previous studies consider a single output measure and do not consider input costs. [2]

Our findings differ from most prior research. When updating the cost frontier as more information gets incorporated into the panel data model, we find little evidence of scale economies and some evidence of scale diseconomies. Moreover, the consideration of input prices and the analysis of the industry using a multi-year sample generally reveal smaller inefficiencies than those identified in other studies. The results also show that the efficiency effects of the type of REIT management differ according to the output measure used to calculate efficiency. When we use revenue to measure output, self-management generally, but not always, associates with more efficiency; but when we measure output with assets, external management uniformly associates with more efficiency across all sample periods. Also contrary to prior research, higher leverage associates with more efficiency. Finally, the results further suggest, in three of our four specifications, that REIT inefficiency increases over time.

---

[1] Viewed another way, our method rules out technological regress over time, which can occur n stochastic frontier estimations that employ year-by-year cross-section estimation. By retaining all prior years as new data get added to the sample, the old technology still exists in the data and will anchor the frontier, if the new year's cross-section will by itself exhibit technical regress.

[2] This study does not perform the first panel-data study on REIT efficiency. Miller, Clauretie and Springer (2006) use input costs, panel data, and two output measures. Our study introduces a more refined and improved methodology that measures efficiency without holding the cost frontier constant over time.

The paper proceeds as follows. The next section reviews the existing literature for both efficiency studies, in general, and for REITs, in particular. Section III discusses the stochastic-frontier, panel-data methodology used to estimate REIT operating efficiency. Section IV reports and interprets the results of our analysis. Section V concludes.

II. Literature review

Cost scale and efficiency studies, using frontier techniques, comprise a substantial literature. The application of production and cost frontier analysis to the financial services industry, however, remains controversial. The controversy stems from, at least, two sources -- the general debate in the empirical production analysis literature and the peculiarities of the financial firm.

Approaches to Frontier Estimation

Most reviews of frontier estimation begin with the classic paper by Farrell (1957), which introduces the basic framework for studying and measuring inefficiency, defined as deviations of actual from "optimum behavior." The frontier establishes the optimum benchmark against which to calculate deviations. Various methods, using statistical and mathematical programming techniques, exist for the construction-estimation of the relevant frontier. A general distinction emerges between deterministic and stochastic frontiers. Deterministic frontiers by construction fix the frontier in the relevant space and encompass all sample observations. Thus, a small subset of data supports the frontier, making it more prone to sampling, outlier, and statistical noise problems, which may distort the measurement of efficiency.[3]

Stochastic frontiers avoid some of the problems associated with deterministic frontiers by explicitly considering the stochastic properties of the data, and distinguishing through a composite

[3] Van den Broek, Førsund, Hjalmarsson, and Meeusen (1980) provide much discussion and empirical evidence.

error term between firm-specific effects, and random shocks or statistical noise. Here, the frontier can shift from one observation to the next, being random rather than exact.

Other problems still exist, however, with the stochastic-frontier approach. First, implementation requires the choice of an explicit functional form for the production or cost function, the appropriateness of which raises questions. The use of a flexible functional form, such as the translog, helps to alleviate this concern to some extent.

Second, the researcher imposes strong distributional assumptions on the error term. While debate continues, some evidence suggests a limited effect of distributional assumptions on the obtained estimates (e.g., Cowing, Reifschneider, and Stevenson 1983, and Greene 1990). Moreover, the relative rankings of firms based on inefficiency calculations seem unaffected. But, the absolute levels of inefficiencies differ over different distributional assumptions on the one-sided error term, with "... the single parameter models ... providing a more pessimistic impression than warranted." (Greene 1990, p. 158).

Frontier Studies of Real Estate Investment Trust Scale and Efficiency

Examination of REIT economies of scale predates REIT efficiency studies. Bers and Springer (1997, 1998a,b) and Ambrose and Pennington-Cross (2000) employ the standard approach of estimating the cost function without allowing for the possibility of inefficient production (i.e., production above the efficient cost function). They all report evidence of economies of scale for REITs.

We know of five frontier studies of REIT operating efficiency. Two papers employ data envelopment analysis (DEA). Anderson, Springer, Fok, and Webb (2002) use DEA to calculate economies of scale and inefficiency for REITs for a 1992-1996 sample. They find extremely large inefficiencies, ranging from 45 to 60 percent. Anderson and Springer (2003) calculate REIT efficiency, using DEA for a 1995-1999 sample, and then use that measure as an indicator for portfolio selection. Although not the main focus of their paper, they also report extremely large levels of inefficiency.

Lewis, Springer, and Anderson (2003) estimate a stochastic frontier that incorporates Bayesian statistics to calculate economies of scale and inefficiency for REITs over the 1995 to 1997 period. They report much lower levels of inefficiency than either of the DEA studies.[4] Using the Bayesian stochastic frontier methodology, they also determine on a case-by-case basis whether inefficiency differs between REITs because of (1) management type (i.e., self or externally managed), (2) leverage (i.e., high or low leverage), and (3) portfolio diversification (i.e., specialized or diversified).[5] They find that self-management associates with higher efficiency in 1995 and 1996, but with lower efficiency in 1997. The 1997 finding raises some concern, since it proves inconsistent with prior work (Bers and Springer 1998b and Anderson, Springer, Fok, and Webb 2002). Higher leverage REITs exhibit higher inefficiency than lower leverage REITs in all three years. Finally, REIT diversification does not affect efficiency, contrary to some of the existing evidence (Bers and Springer 1998b and Anderson, Springer, Fok, and Webb 2002).[6]

The most recent frontier study (Miller, Clauretie, and Springer, 2006) also uses the stochastic-frontier methodology using a panel data sample from 1995 to 2003. They propose two measures of output and develop two measures of input prices, missing from most prior studies. They use the entire panel-data sample to estimate the stochastic frontier and calculate the

---

[4] Since DEA frontiers encompass the entire data set while the stochastic frontier permits individual points to lie outside the frontier, finding larger inefficiencies for DEA frontiers relative to stochastic frontiers makes intuitive sense.

[5] A dummy variable captures whether the REIT experiences external or self-management. High debt REITs hold a debt ratio above 67 percent. Finally, a Hirschman-Herfindhal index above 80 percent identifies a focused- or non-diversified portfolio.

[6] Ambrose, Highfield, and Linneman (2005) also use a stochastic-frontier approach. Using data from 1990 to 2001, they find scale economies. They consider the stochastic-frontier specification in their penultimate section. The description of the model and its estimation prove sketchy, at best.

economies of scale and efficiency measures. Their model implicitly assumes that the available production plans or technology did not change over the sample period. They find some evidence that economies of scale existed in the 1995 to 1997 period, but had disappeared by the 1998 to 2000 period. Finally, in the 2001 to 2003 period, some evidence of diseconomies of scale emerges. Furthermore, they conclude that REITs exhibit much smaller levels of inefficiency than previously reported in the literature.

While not uniform across studies, many measure output as total assets or by dividing total assets into sub-categories. For the DEA studies, inputs reflect total cost or its sub-components – interest expense, operating expense, general and administrative expense, and management fees. For the stochastic frontier studies, only one includes input prices, which normally occurs in stochastic frontier analysis. Lewis, Springer, and Anderson (2003) do not introduce any input prices, but only include output in the translog cost function.[7] Ambrose, Highfield, and Linneman (2005) apparently use input costs rather than input prices in their stochastic-frontier model. Miller, Clauretie, and Springer (2006), the exception, introduce two proxies for input prices – interest expense per dollar of debt and other expense per dollar of assets.

Our analysis differs from Miller, Clauretie, and Springer (2006) in an important methodological respect. They estimate one frontier for the entire 1995 to 2003 sample period, implicitly assuming that no technological improvement occurred over time. For example, the frontier employs 2003 information to estimate the benchmark frontier for measuring efficiency for REITs operating in 1995.[8] We only use information available each year to estimate the benchmark

[7] That translog cost function appears in Bers and Springer (1998a,b).

[8] Miller, Clauretie, and Springer (2006) do break their sample into three subperiods – 1995 to 1997, 1998 to 2000, and 2001 to 2003. But, once again, they estimate the benchmark frontier for measuring inefficiency for all REITs in each subperiod using the entire subsample. Thus, for example, the inefficiency of a REAT in 1995 uses the frontier estimated with data from 1995 to 1997.

frontier for that year. For example, we employ data from 1995 to 2000 to estimate the benchmark for calculating inefficiency for REITs operating in 2000. As a result, all findings reported in Miller, Clauretie, and Springer (2006) potentially could change when we consider different benchmark frontiers for each year covered in our sample (i.e., 1998 to 2003).

III. Methodology

Aigner, Lovell, and Schmidt (1977) and Meeusen and Van den Broeck (1977) first introduce the stochastic-frontier model, where a stochastic frontier provides an upper bound on actual production or a lower bound on actual cost. The basic model assumes a composite error term that sums a two-sided error term, measuring all effects outside the firm's control, and a one-sided, non-negative error term, measuring technical inefficiency. A firm can lie on or within the frontier, and the distance between actual output and the frontier output represents technical inefficiency. The early articles on stochastic frontiers used cross-section data. With panel data, however, later models (Cornwell, Schmidt, and Sickles, 1990; Kumbhakar, 1990; Battese and Coelli, 1992) include time-varying inefficiency.

As alluded to above, the use of panel data opens an important question concerning what data to employ to capture the production plans or technology available for the firms. Tulkens and vander Eeckart (1995) offer several possible scenarios. First, the researcher can opt to use the cross-section of firms in each year to represent the potential production plans or technology. That approach implicitly assumes that past and future production plans or technologies do not play any role in determining the frontier for the current time period. We call this approach the no-memory method, indicating that no information (no memory) other than the current period enters into the calculation of the frontier. For REITs, Lewis, Springer, and Anderson (2003) implement this method.

At the other extreme, the researcher can use the entire panel data set to define the frontier for each and every firm in each and every year. In this case, all existing production plans or technologies in the panel data provide the information for specifying the frontier. Such an approach probably makes the most sense in an industry where the production plans or technology does not change rapidly. We call this approach the perfect forward- and backward-looking method, indicating that all information (past, current, and future memory) enters into the calculation of the frontier. Miller, Clauretie, and Springer (2006) adopt this method to study REIT efficiency

Finally, a middle ground exists whereby the current period incorporates the production plans or technologies of the current and all past periods.[9] That is, the past information on how to organize production does not disappear from the memory of the firms in the current period. As such, this assumption rules out technical regress, since last period's production plans or technology appears in this period's information set. We call this approach the perfect backward-looking method, indicating that all current and past information (past and current memory) enters into the calculation of the frontier.

We adopt the perfect backward-looking method for our analysis in this paper. Thus, we estimate the frontier cost curve in each period, say 1999, using all prior years and the current year, that is, 1995 to 1999, in the estimation. Then we calculate the efficiency and economies of scale only for the last year in the sample period used, that is, 1999. The calculation of efficiency in a prior year, say 1998, comes from estimating the cost frontier using the sample period that ends in that year, that is, 1995 to 1998. In sum we calculate the efficiencies and cost elasticities

---

[9] Charnes, Clark, Cooper, and Golney (1985) use a special case of this third option called windows analysis. This approach employs a fixed window size so that when the researcher moves to the next time period, the earliest time period in the window drops out as the new time period gets added. The third approach discussed in the text employs a variable window size that increases by one when the researcher moves to the next time period in the sample. That is, once information enters the stock of technical knowledge, it does not disappear or depreciate as time advances.

for REITs in 1998, 1999, …, and 2003, estimating the frontiers from data sets of 1995 to 1998, 1995 to 1999, …, and 1995-2003, respectively.

The Framework

In the present study, we view the REIT firm as an intermediary, operating in competitive markets and using a multiple input-output technology. The concept of efficiency (and, thus, inefficiency), although well rooted in the history of economic thought, possesses a normative character, which is reinforced by the short list of inputs normally considered in empirical models.[10] Our interpretation accords with the widely held view of production as a systematic technical relationship of inputs and outputs, and with the observation that firms can survive in markets for extended periods, even though they appear to operate at relatively lower levels of efficiency.

Our analysis proceeds as follows. We specify and estimate a composite-error model. This model separates firm-specific effects, captured by the one-sided error term (u_{it}), from random shocks and statistical noise, reflected by the two-sided, symmetric error term (v_{it}), and permits the estimation of firm-specific deviations, using the method of Jondrow, Lovell, Materov, and Schmidt (1982). We also evaluate the role of some other firm-specific factors that may affect the level of inefficiency by specifying the one-sided error term as depending on these additional control variables (Battese and Coelli 1995; Coelli 1996).

The Model

We estimate a translog variable cost function with a composite error term (ε_{it}) that can be written as follows (we drop REIT and time subscripts to simplify):

[10] Stigler (1976) discusses these issues with some insightful observations.

(1)
$$\begin{aligned} ln\,C = \alpha_0 + \sum_{i=1}^{m} \alpha_i \, ln\, q_i + \sum_{j=1}^{n} \beta_j \, ln(1+p_j) + \sum_{i=1}^{m}\sum_{r=1}^{m} \pi_{ir} \, ln\, q_i \, ln\, q_r \\ + \sum_{j=1}^{n}\sum_{k=1}^{n} \delta_{jk} \, ln(1+p_j)\, ln(1+p_k) + \sum_{i=1}^{m}\sum_{j=1}^{n} \phi_{ij} \, ln\, q_i \, ln(1+p_j) + \varepsilon, \end{aligned}$$

where lnC = the natural logarithm of the cost; lnq_i = the natural logarithm of the i^{th} output ($i=1,...,m$); $ln(1+p_j)$ = the natural logarithm of one plus the j^{th} input price ($j=1,...,n$); $\varepsilon = v + u$ with $v \approx N(0, \sigma^2_v)$ and $u \approx N(m, \sigma^2_u)$, a truncated normal; $m = \theta_0 + \sum_{s=1}^{q} \theta_s x_s + w$; x_s = alternative control variables; w = a two-sided, symmetric random error $\approx N(0, \sigma^2_w)$; and $\alpha, \beta, \pi, \delta, \phi$, and θ equal coefficients. Since a few observations for p_j equal zero, we took the natural logarithm of $(1 + p_j)$ so as to not lose those observations.

The technical efficiency index for each firm in the sample is given as follows (Battese and Coelli 1995; and Coelli 1996):

(2)
$$TE = exp(u) = exp(\theta_0 + \sum_{s=1}^{q} \theta_s x_s + w).$$

We adopt the translog cost function for two basic reasons. First, it imposes virtually no restrictions on the first- and second-order effects. At the same time, it also provides a second-order logarithmic approximation to an arbitrary continuous transformation surface.[11] Second, the dual approach, although not free of problems itself, allows the bypassing of the well-known problems of multicollinearity that inherently plagues the direct approach. The reliability of our results hinges, of course, on the validity of the cost-minimization assumption.

The Data

---

[11] Previous research on the cost structure of commercial banks concludes in favor of our specification. For example, Lawrence (1989) rejects both the more-restrictive Cobb-Douglas specification and the more-flexible Box-Cox transformation in favor of the translog. Also, Noulas, Ray, and Miller (1990a), using Call Report data for large banks, conclude against homotheticity, constant returns to scale, and so on, while Noulas, Miller, and Ray (1993) demonstrate the instability of the findings from alternative Box-Cox transformations.

Our data include 1995 to 2003 information on publicly traded REITs listed in the *National Association of Real Estate Investment Trusts (NAREIT) Handbook* and the *SNL REIT DataSource*. Due to missing values, the final sample consists of 212, 221, 222, 236, 233, 220, 208, 198, and 132 REITs in 1995, 1996, …, and 2003, respectively, for a total of 1851 observations.[12] Table 1 reports summary statistics.

Prior research has favored the use of total assets as the measure of REIT output. Lewis, Springer, and Anderson (2003) use total assets and market capitalization (i.e., share price times the number of shares) as alternative measures of output and conclude that total assets perform the best. Following Miller, Clauretie, and Springer (2006), we use two alternative aggregate measures of output (q), total assets and total revenue. That is, the translog cost function includes only one output, but we estimate two separate specifications, one for total assets and one for total revenue.

Prior research (Bers and Springer 1998a,b; Lewis, Springer, and Anderson 2003) does not incorporate input prices.[13] While the data source puts a severe constraint on generating input prices, Miller, Clauretie, and Springer (2006) construct two proxies for input prices. We adopt their approach, calculating the input prices as follows: the average interest cost per dollar of debt (average price of debt, i) and the average other expenses per dollar of assets (average price of other inputs, r). The dependent variable for the translog panel model is total cost (C), which includes (1) interest expense, (2) operating expense, (3) general and administrative expense, and (4) management fees.

The stochastic cost function includes one output and two input prices. We also introduce one control variable to control for different levels of debt. More specifically, we include the debt-

[12] In addition to missing values, we deleted all observations with a debt-to-asset ratio exceeding one.

[13] Ambrose, Highfield, and Linneman (2005) apparently use input costs, not input prices, in their stochastic-frontier model estimation.

to-asset ratio, *Debt-Ratio*, as a continuous variable that effectively shifts the cost frontier. Generally, a more leveraged REIT should face higher costs because the debt-service cost is higher. Moreover, REITs do not garner any tax shield effect because the interest expense offers no tax advantage.

The prior discussion focuses on the specification of the frontier cost function. That is, what cost frontier associates with a 100-perfcent efficient REIT, given the available technology. The estimation technique of the stochastic frontier includes a one-sided error term that captures inefficiency deviations above the stochastic cost frontier. We also consider those variables that may affect the inefficiency of each REIT.

First, we introduce the *Debt-Ratio* as such a variable. This variable decides whether higher-debt REITs show different efficiency levels in comparison to lower-debt REITs.[14] More leverage may associate with more efficiency, however, because management may monitor more closely the activities of outsiders, specifically creditors.

Next, we include a dummy variable, *Self-Managed*, that equals one, if the REIT is self-managed. This variable determines whether self-managed REITs prove more cost efficient than externally managed REITs. Self-managed REITs use internal staff to make investment and managerial decisions. Externally managed REITs hire outside advisory firms to make these decisions. Potential agency problems arise from a misalignment of incentives caused by the compensation structure when a REIT uses an outside advisor (Sagalyn 1996). Capozza and Seguin (2000) document that most external advisors receive compensation based on a percentage of assets and/or property-level cash flows. They demonstrate that externally managed REITs underperform internally managed (self-managed) REITs. Because the outside advisor typically

[14] Remember that we also allow total cost to adjust due to differences in leverage.

benefits by having more properties, externally advised REITs generally experience higher leverage. Capozza and Seguin (2000) note that when external advisors receive compensation as a percentage of assets or cash flow, they possess little incentive to negotiate favorable terms on the debt, because interest expenses probably do not affect their compensation. A primary source of the underperformance of externally managed REITs relates to the use of debt with above market interest rates.[15]

Finally, we add a variable to explain changes in efficiency over time. The time variable (i.e., *Time = 1, 2, …,* and *9,* corresponding to *1995, 1996, …,* and *2003*, respectively) measures whether REITs became more or less cost efficient over the sample period. For example, the rapid growth in the size of the average REIT, mentioned in the introduction, may cause inefficiency to rise as managers find it difficult to accommodate rapid growth efficiently.

IV. Results

Tables 2 through 7 present the estimated cost frontiers, using panel data sets 1995 to 1998, 1995 to 1999, …, and 1995 to 2003, respectively, for output defined as total assets and total revenue. We report results for specifications without (simple model) and with (complex model) input prices. The precise estimating equations emerge from equations (1) and (2) as follows:

$$\begin{aligned} ln\,Cost = {} & \alpha_0^1 + \alpha_1^1 \cdot ln\,Asset + \pi_{11}^1 \cdot ln\,Asset \cdot ln\,Asset \\ & + \gamma_1^1 \cdot Debt\text{-}Ratio + v^1 + u^1; \end{aligned} \tag{3}$$

$$\begin{aligned} ln\,Cost = {} & \alpha_0^2 + \alpha_1^2 \cdot ln\,Asset + \pi_{11}^2 \cdot ln\,Asset \cdot ln\,Asset + \beta_1^2 \cdot ln(1+i) \\ & + \delta_{11}^2 \cdot ln(1+i) \cdot ln(1+i) + \beta_2^2 \cdot ln(1+r) + \delta_{22}^2 \cdot ln(1+r) \cdot ln(1+r) \\ & + \phi_{12}^2 \cdot ln\,Asset \cdot ln(1+i) + \phi_{13}^2 \cdot ln\,Asset \cdot ln(1+r) \\ & + \phi_{23}^2 \cdot ln(1+i) \cdot ln(1+r) + \gamma_1^2 \cdot Debt\text{-}Ratio + v^2 + u^2; \end{aligned} \tag{4}$$

---

[15] Also, Ambrose and Linneman (2001) note that externally advised REITs have altered their operating characteristics, such as debt use, to become more competitive with self-managed REITs.

(5)
$$\begin{aligned} \ln Cost = \alpha_0^3 + \alpha_1^3 \cdot \ln Revenue + \pi_{11}^3 \cdot \ln Revenue \cdot \ln Revenue \\ + \gamma_1^3 Debt\text{-}Ratio + v^3 + u^3; \end{aligned}$$

(6)
$$\begin{aligned} \ln Cost = {} & \alpha_0^4 + \alpha_1^4 \cdot \ln Revenue + \pi_{11}^4 \cdot \ln Revenue \cdot \ln Revenue \\ & + \beta_1^4 \cdot \ln(1+i) + \delta_{11}^4 \cdot \ln(1+i) \cdot \ln(1+i) + \beta_2^4 \cdot \ln(1+r) \\ & + \delta_{22}^4 \cdot \ln(1+r) \cdot \ln(1+r) + \phi_{12}^4 \cdot \ln Revenue \cdot \ln(1+i) \\ & + \phi_{13}^4 \cdot \ln Revenue \cdot \ln(1+r) + \phi_{23}^4 \cdot \ln(1+i) \cdot \ln(1+r) \\ & + \gamma_1^4 \cdot Debt\text{-}Ratio + v^4 + u^4; \end{aligned}$$

(7)
$$\begin{aligned} TE^i = \exp(u^i) = \exp(\theta_0^i + \theta_1^i \cdot Time + \theta_2^i \cdot Self\text{-}Managed \\ + \theta_3^i \cdot Debt\text{-}Ratio + w^i), \ \ where \quad i = 1 \ to \ 4. \end{aligned}$$

We link the appropriate error specifications in equation (7) to their counterparts in equations (3), (4), (5), and (6) and perform a stochastic frontier estimation.

Given our approach of the perfect backward-looking method, we report estimated models for each year from 1998 to 2003. A comparison of the coefficients over time permits us to determine whether cost technology improves. More specifically, adding a year to the sample can alter coefficients in two ways. First, if cost technology improves, then the frontier shifts downward, lowering cost for a given level of output. In this case, the coefficients that define the cost frontier must change from year to year. On the other hand, if cost technology does not improve, the frontier does not shift and the coefficients that define the frontier should not change from year to year. Second, the coefficients that define how inefficiency responds to its determinants may also adjust. In this case, we argue that such shifts imply a fragile, non-robust relationship.

Shifting Cost Frontiers

First, we address the question of whether the cost technology improves over the sample period. In testing for significant differences in the same coefficients between two consecutive models, we find limited evidence of technological shifts. For example, testing for differences between the coefficients that define the cost frontier in Tables 6 and 7 will determine whether the frontier shifted between 2002 and 2003.

No evidence exists of a cost frontier shift between consecutive years with the exception of 1998 and 1999. In this case, the results suggest a frontier shift for both the simple and the complex specifications when revenue measures output and for the complex specification only when assets measure output. For 1998 and 1999, although the coefficient of the debt ratio does not change significantly, nearly every other coefficient experiences a significant adjustment. For all other years, no evidence emerges to indicate that the frontier shifts because of improved technology. In all specifications, the debt ratio associates positively with the total cost. That is, as expected, a higher debt ratio raises the REIT's frontier cost of operation.

We searched for regulatory or structural changes as possible explanations for the shift in the frontier between 1998 and 1999. But no compelling story emerges. First, the REIT Simplification Act of 1997 became effective in 1998. This Act implemented a number of tax-law changes, but no one of them should exhibit dramatic effects. Second, analysts refer to the 1992 to 2001 as the REIT modernization era. In both cases, we see numerous small changes. The cumulative effect of these small changes could precipitate a one-time shift in the cost frontier, once a threshold is crossed. At the moment, however, our argument proves highly speculative.

Inefficiency Model

Next, we consider the inefficiency model. The estimate of gamma provides a test of whether a frontier model makes sense in the first place. We note that gamma proves insignificant at the 5-percent level for the complex specification with output measured by assets in Tables 2, 3, 4, and 7. Moreover, even when it is significant, gamma exhibits an extremely small value for this model relative to the other specifications. Finally, the coefficients of the explanatory variables generally prove insignificant for this specification. In sum, this specification may imply no inefficiency in the REIT industry over the 1998 to 2003 sample period. Thus, we largely ignore further comments on the complex specification of the inefficiency model using total assets as the output measure.

To interpret the constant and the coefficients in the inefficiency specification, consider the simple model with output defined as assets and the estimates reported in Table 7. The constant in the estimation of the mean of the one-sided inefficiency term equals –1.6301. Since we estimate the mean of the truncated normal distribution function that captures the inefficiency, a negative mean implies that the normal distribution locates to the left of the origin. The distribution truncates the negative values, leaving only the right-side tail of the distribution. Now, consider the coefficient of self-management of 0.5978. For self-managed REITs, the self-management variable equals 1 and the new mean of the truncated normal distribution equals –1.0323 (= –1.6301 + 0.5978). Thus, the distribution shifts to the right and the size of the truncated tail used to calculate the inefficiency becomes larger, implying that inefficiency rises. In sum, self-managed REITs generate more inefficiency in the specification closest to the Lewis, Springer, and Anderson (2003) model. They find that self-management reduces inefficiency in 1995 and 1996, but increases inefficiency in 1997. The estimates in Table 7 consider the period from 1995 to 2003 and shows that for this specification self-management increases inefficiency, on average.[16]

For all specifications with a significant gamma, the debt ratio shows a significant and negative effect on inefficiency in all sample periods, save one. That is, a higher debt ratio generally associates with higher efficiency. This finding matches the results of Miller, Clauretie, and Springer (2006), but counters those of Lewis, Springer, and Anderson (2003) from their Bayesian

---

[16] For the simple specification with output measured by assets, all estimates of the coefficient of the self-managed dummy variable produce a significant and positive value.

stochastic frontier specification.[17] More specifically, we find a significant effect whereby REITs using more leverage operate on a higher cost frontier. But, given this finding, higher leverage REITs must exercise much more care in their operations, achieving higher efficiency than their lower-leveraged colleagues. Lewis, Springer, and Anderson (2003) do not use the debt-to-asset ratio to shift their cost frontier. Thus, the effect of the debt-to-asset ratio on the cost function dominates its effect on improving efficiency, probably leading to their conclusion that a high debt-to-asset ratio REIT exhibits more inefficiency (less efficiency).

The remaining two explanatory variables – time and self-management – show different outcomes over time and across specifications. Self-managed REITs exhibit higher inefficiency in the simple model with output measured by assets across all time periods. Self-managed REITs generally exhibit lower inefficiency in both models with output measured by revenue, except in 1999 and 2000 (Tables 3 and 4). The former finding proves consistent with the results of Bers and Springer (1998b) and Anderson, Springer, Fok, and Webb (2002). The latter proves consistent with Lewis, Springer, and Anderson (2003). Because REITs report assets on a cost basis, measuring output with assets does not capture managerial efforts to enhance asset value. Moreover, revenue correlates more directly with value. Thus, in this instance, measuring output with revenue may better reflect the managerial goal of maximizing shareholder value.

Finally, for the simple specifications, time reduces inefficiency in 1998 and 1999 (Tables 2 and 3), but increases inefficiency in 2000 through 2003 (Tables 4 through 7). For the complex specification with output measured by revenue, inefficiency consistently increases with time across all years. The bulk of the evidence suggests that REITs become more inefficient over time. We

---

[17] We do not consider the portfolio diversification variable. But, Lewis, Springer, and Anderson (2003) find that this variable does not generate a consistent effect on REIT inefficiency. Also, a key difference exists between our findings and those of Lewis, Springer, and Anderson (2003). They consider the effects of self-management, the debt ratio, and portfolio diversification on a case-by-case basis. We include all control variables simultaneously. Further, our specification of the frontier cost function includes the debt-to-asset ratio as a shift variable.

initially anticipated that REITs would improve their efficiency over time, since improved methods of operation should lower cost. It seems unlikely that REITs become less efficient over time without some external stimulus. The rapid growth in the size of REITs over the past 15 years may explain this increase in inefficiency. Perhaps, management could not keep up with the growth. Also, in an expanding REIT industry, the transactions costs of growth may distort the expense measurement relative to the expenses of operating a relatively stabilized property portfolio. Also, changes in the regulatory environment may have contributed to increased inefficiency.[18]

Economies and Diseconomies of Scale

The model estimates permit the calculation of economies of scale. The measure of economies of scale equals the cost elasticity with respect to output – either assets or revenue. That is, the cost elasticity with respect to output equals the partial derivative of the logarithmic cost functions in equations (3), (4), (5), and (6) with respect to the logarithm of output. For example, the cost elasticity with respect to output in equation (4) where assets measure output equals the following relation:

$$\frac{\partial\, ln\, Cost}{\partial\, ln\ Assets} = \alpha_1^2 + 2 \cdot \pi_{11}^2 \cdot ln\ Assets + \phi_{12}^2 \cdot ln(1+i) + \phi_{13}^2 \cdot ln(1+r)\ . \tag{8}$$

Using the coefficients from Table 7, we get the exact calculation as follows:

$$\frac{\partial\, ln\, Cost}{\partial\, ln\ Assets} = 1.0166 + 2 \cdot 0.0005 \cdot ln\ Assets - 0.1027 \cdot ln(1+i) + 0.0129 \cdot ln(1+r)\ , \tag{9}$$

where we need to include values for *lnAssets*, *ln(1+i)*, and *ln(1+r)* for each REIT and each time period. Table 8 reports the average cost elasticity with respect to output. We calculate the cost elasticity for each REIT in the final year of the sample period used to estimate the cost frontier. For

[18] In discussing the possible explanations for the significant shift in the frontier between 1998 and 1999, we discussed the REIT Simplification Act of 1997, which altered many tax laws. The REIT Modernization Act of 1999, became effective in 2001.

example, we estimate the average cost elasticity for REITs in 2002 using the frontier estimated from the 1995 to 2002 sample period.

Except for the specification in equation (4), the cost elasticity does not differ significantly from one implying trivial, if any, economies or diseconomies of scale. The specification in equation (4) suggests that diseconomies of scale exist, since the cost elasticity significantly exceeds one in 2001, 2002, and 2003, but does not significantly differ from one in 1998, 1999, and 2000. Lewis, Springer, and Anderson (2003) report economies (increasing returns) to scale for 1995, 1996, and 1997, using assets as the measure of output. Bers and Springer (1997, 1998a,b) and Anderson, Springer, Fok, and Webb (2002) also report economies of scale for samples of REITs in the 1990s. The limited evidence for diseconomies of scale diminishes when we use revenue as output or when we exclude the input price control variables.[19] Our findings prove generally consistent with those of Miller, Clauretie, and Springer (2006).

Inefficiency Estimates

Table 9 reports the inefficiency estimates from our various specifications and sample periods. As before, we calculate the inefficiency for each REIT in the final year of the sample period used to estimate the cost frontier. For example, we calculate the inefficiency for REITs in 2000 relative to the frontier estimated from the 1995 to 2000 sample period.

The lowest inefficiency emerges for the complex specification with output measured by assets. But, this specification also shows an extremely small and frequently insignificant gamma value, implying that the frontier approach did not apply. In other words, a small and insignificant gamma suggests that inefficiency does not exist, corresponding to the small estimates of inefficiency. The simple specification with output measured by assets exhibits the most

[19] Bers and Springer (1997) do find that the number of REITs exhibiting economies of scale diminishes with the inclusion of other control variables

inefficiency of about 100 percent on average over the 1998 to 2003 period.[20] The specifications with output measured by revenue generate average inefficiencies of around 20 and 15 percent for the simple and complex specifications, respectively. Our inefficiency estimates generally prove consistent with Miller, Clauretie, and Springer (2006) and are generally smaller than those of Lewis, Springer, and Anderson (2003), who report dramatic reductions in inefficiency estimates when using the Bayesian stochastic frontier specification rather than DEA.

V. Conclusions

The results show that the estimated returns to scale for publicly traded REITs do not support economies of scale. That is, our findings suggest no scale economies, but provide some evidence for diseconomies of scale. Previous studies generally find economies of scale. Those studies use older data and cross-section analysis. Our panel-data model extends the coverage through 2003. The rapid growth in the size of REITs may have exhausted the economies of scale for all but the smaller firms in the industry. That is, given the dramatic growth in average REIT size over the sample period, the movement from no economies of scale early in the sample period to diseconomies of scale at the end of the sample period makes intuitive sense.

Consistent with the findings of many prior studies, Miller, Clauretie, and Springer (2006) identify possible economies of scale during the 1995 to 1997 period. Their methodology applies the same frontier to all REITs in the sample period. That is, when they estimate the model using the 1995 to 1997 sample period, they calculate the cost elasticity estimate for all REITs in the three-year period. This paper uses the panel data set, say 1995 to 1998, to estimate the frontier, assuming the perfect backward-looking method. Then we use the estimated frontier to determine the cost elasticity only for those REITs in the most recent year, in this case 1998. As such, we find

[20] Note that 100-percent inefficiency means that the actual cost doubles the minimum cost of that output. Thus, over 100-percent inefficiency in cost proves feasible.

no evidence of economies of scale, but we begin our examination only in 1998, by which time Miller, Clauretie, and Springer (2006) conclude that economies of scale no longer exist in the industry. Thus, our current findings do not convey a different story from those of Miller, Clauretie, and Springer (2006).

The initial tests of REIT efficiency using DEA report large inefficiencies (Anderson, Springer, Fok, and Webb, 2002; Anderson and Springer, 2003). Lewis, Springer, and Anderson (2003) use a stochastic frontier and find much lower levels of inefficiency than either of the DEA studies. This study generally documents even lower inefficiencies. But, we also find that inefficiencies increase over time, consistent with the findings of Miller, Clauretie, and Springer (2006).

The finding that a higher debt-to-asset ratio associates with more efficiency runs counter to the findings of Lewis, Springer, and Anderson (2003). Unlike Lewis, Springer, and Anderson (2003), we employ the debt-to-asset ratio to shift the frontier cost function as well as to explain the one-sided (inefficiency) error term. We find that higher leverage raises the cost frontier and lowers inefficiency. Jensen (1986) argues that higher leverage can induce less efficiency through agency problems between managers and owners or more efficiency due to more intense external monitoring. Our results conform to that latter view.

Our results also offer some apparent contradictions to conventional wisdom as well as further insight into the REIT industry's rapid growth. Conventional wisdom and most prior research suggest that self-managed REITs exhibit more efficiency than the alternatives, namely affiliate- or third-party managed REITs. Our results indicate different outcomes depending on the measure of output. When we measure output with assets, self-management associates with more inefficiency. Capozza and Seguin (2000) note that external advisers frequently receive compensation tied to assets. This may explain why external advisers prove more efficient when assets measure output. When we measure output with revenue, self-management exhibits more efficiency, the opposite outcome. We propose that revenue better captures the goal of internal managers to maximize shareholder value. Thus, managers expend much effort to wring additional revenue out of their firm with much less concern about firm size, as measured by assets. In sum, we argue that the contradictory results on the effect of the self-management dummy variable supports the use of revenue over assets as a measure of output in REIT economies-of-scale and efficiency studies.

References:

Afriat, S. N., 1972. "Efficiency Estimation of Production Functions." *International Economic Review* 13, 568-98.

Aigner, D. J. and S. F. Chu, 1968. "On Estimating the Industry Production Function." *American Economic Review* 58, 826-39.

Aigner, D. J., C. A. K. Lovell, and P. Schmidt, 1977. "Formulation and Estimation of Stochastic Frontier Function Models." *Journal of Econometrics* 6, 21-37.

Ambrose, B. W., M. J. Highfield, and P. Linneman, 2005. "Real Estate and Economies of Scale: The Case of REITs." *Real Estate Economics* 33:2.

Ambrose, B.W. and P. Linneman. 2001. "REIT Organizational Structure and Operating Characteristics." *Journal of Real Estate Research* 21:3, 141-162.

Ambrose, B. W., and A. Pennington-Cross, 2000. "Economies of Scale on Multi-Product Firms: The Case of REITs." Published Working Paper, Real Estate Research Institute, Bloomington, IN.

Anderson, R. I., D. Lewis, and T. M. Springer, 2000. "Operating Efficiencies in Real Estate: A Review of the Literature." *Journal of Real Estate Literature* 8:1, 3-20.

Anderson, R. I., and T. M. Springer, 2003. "REIT Selection and Portfolio Construction: Using Operating Efficiency as an Indicator of Performance." *Journal of Real Estate Portfolio Management* 9:1 17-28.

Anderson, R. I., T. M. Springer, R. Fok, and J. R. Webb, 2002. "Technical Efficiencies and Economies of Scale: A NonParametric Analysis of REIT Operating Efficiency." *European Journal of Operational Research*

Banker, R.. D., and A. Maindiratta, 1992. "Maximum Likelihood Estimation on Monotone and Concave Production Frontiers." *Journal of Productivity Analysis* 3, 401-15.

Battese, G. E, and T. J. Coelli, 1992. "Frontier Production Functions, Technical Efficiency, and Panel Data: With Applications to Paddy Farmers in India." *Journal of Productivity Analysis* 3: 153-169.

Battese G. E., and T. J. Coelli, 1995. "A Model of Technical Inefficiency effects in a Stochastic Frontier Production Function for Panel Data." *Empirical Economics* 20, 352-332.

Bauer, P. W., 1990. "Recent Developments in the Econometric Estimation of Frontiers." *Journal of Econometrics* 46, 39-56.

Berger, A. N., and D. B. Humphrey, 1991. "The Dominance of Inefficiencies Over Scale and Product Mix Economies in Banking." *Journal of Monetary Economics* 28, 117-48.

Bers, M., and T. M. Springer, 1997. “Economies-of-Scale for Real Estate Investment Trusts.” *Journal of Real Estate Research* 14:3, 275-290.

Bers, M., and T. M. Springer, 1998a. “Sources of Scale Economies for Real Estate Investment Trusts.” *Real Estate Finance* (Winter/Spring) 37-44.

Bers, M., and T. M. Springer, 1998b. “Differences in Scale Economies Among Real Estate Investment Trusts: More Evidence.” *Real Estate Finance* (Fall) 37-44.

Capozza, D.R. and P. J. Seguin, 2000. “Debt, Agency and Management Contracts in REITs: The External Advisor Puzzle.” *Journal of Real Estate Finance and Economics*, 20:2, 91-116.

Coelli, T. J., 1996. “A Guide to FRONTIER Version 4.1: A Computer Program for Stochastic Frontier Production and Cost Function Estimation.” CEPA Working Paper 97/07, Center for Efficiency and Productivity Analysis, University of New England, Armidale.

Cornwell, C., P. Schmidt, and R. C. Sickles, 1990. “ Production Frontier with Cross-Sectional and Times-Series Variation in Efficiency Levels.” *Journal of Econometrics* 46: 185-200.

Cowing, T. G., D. Reifschneider, and R. E. Stevenson, 1983. "A Comparison of Alternative Frontier Cost Function Specifications." in *Developments in Econometric Analyses of Productivity*, ed. by Ali Dogramaci, Kluwer-Nijhoff, Chapter 4.

Farrell, M. J., 1957 "The Measurement of Productive Efficiency." *Journal of the Royal Statistical Society* 120 (series A), 253-81.

Førsund, F. R., C. A. K. Lovell, and P. Schmidt, 1980. "A Survey of Frontier Production Functions and of Their Relationship to Efficiency Measurement." *Journal of Econometrics* 13, 5-25.

Greene, W. H., 1990. "A Gamma-Distributed Stochastic Frontier Model." *Journal of Econometrics* 46, 141-63.

Jensen, M. C., 1986. “Agency Costs of Free Cash Flow, Corporate Finance, and Takeovers.” *American Economic Review, Papers and Proceedings* 76, 323-329.

Jondrow, J., C. A. K. Lovell, I. S. Materov, and P. Schmidt, 1982. "On the Estimation of Technical Inefficiency in the Stochastic Frontier Production Function Model." *Journal of Econometrics* 19, 233-38.

Kumbhakar, S. C., 1990. “Production Frontiers, Panel Data, and Time Varying Technical Inefficiency.” *Journal of Econometrics* 27: 201-11.

Lawrence, C., 1989. "Banking Costs, Generalized Functional Forms, and Estimation of Economies of Scale and Scope." *Journal of Money, Credit and Banking* 21, 368-79.

Lewis, D., T. M. Springer, and R. Anderson, 2003. "The Cost Efficiency of Real Estate Investment Trusts: An Analysis with a Bayesian Frontier Model." *The Journal of Real Estate Finance and Economics* 26:1, 65-80.

Linneman, P., 1997. "Forces Changing the Real Estate Industry Forever." *Wharton Real Estate Review* (Spring) 1-12.

Meeusen, W., and J. van den Broek, 1977. "Efficiency Estimation from Cobb-Douglas Production Functions with Composite Errors." *International Economic Review* 18, 435-44.

Miller, S. M., T. M. Clauretie, and T. M. Springer, 2006. "Economies of Scale and Cost Efficiencies: A Panel-Data Stochastic-Frontier Analysis of Real Estate Investment Trusts." *The Manchester School*, in press.

Noulas, A. G., S. C. Ray, and S. M. Miller, 1990. "Returns to Scale and Input Substitution for Large U. S. Banks." *Journal of Money, Credit and Banking* 22, 94-108.

Noulas, A. G., S. M. Miller, and S. C. Ray, 1993. "Economies and Diseconomies of Scope in Large-Sized U. S. Banks." *Journal of Financial Services Research* 7, 235-248.

Richmond, J., 1974 "Estimating the Efficiency of Production." *International Economic Review* 15, 515-21.

Sagalyn, L. B., 1996. "Conflicts of Interest in the Structure of REITs." *Real Estate Finance* 9:2, 34-51.

Schmidt, P., 1985-86. "Frontier Production Functions." *Econometric Reviews* 4, 289-328.

Stigler, G. J., 1976. "The Xistence of X-efficiency." *American Economic Review* 66, 213-38.

Timmer, C. P., 1971. "Using a Probabilistic Frontier Function to Measure Technical Efficiency." *Journal of Political Economy* 79, 776-94.

van den Broek, J., F. R. Førsund, L. Hjalmarsson, and W. Meeusen, 1980. "On the Estimation of Deterministic and Stochastic Frontier Production Functions." *Journal of Econometrics* 13, 117-38.

Vogel, J. H., Jr., 1997. "Why the New Conventional Wisdom About REITs is Wrong." *Real Estate Finance*, 7-12.

Table 1: Summary Statistics

Variable	Average	Median	Maximum	Minimum
lnCost	11.0783	11.2330	15.9116	2.6391
lnAssets	13.2183	13.4453	17.0662	7.2779
lnRevenue	11.3127	11.5140	15.9870	2.0794
ln(1+i)	0.0653	0.0631	1.0756	0.0000
ln(1+r)	0.1051	0.0784	1.7815	0.0012
Time	4.7942	5.0000	9.0000	1.0000
Self-Managed	0.7758	1.0000	1.0000	0.0000
Debt-Ratio	0.4941	0.4881	0.9964	0.0031

Note: The symbol ln stands for the natural logarithm. Cost includes interest expense, operating expense, general and administrative expense, and management fees interest cost on all deposits. Assets equals total assets. Revenue equals total revenue. We calculate the input prices as follows: *i* equals the average interest cost per dollar of debt and *r* equals the average other expenses per dollar of assets. Time runs from 1 to 9 capturing 1995 to 2003. *Self-Managed* equals one for self-managed REITs; 0 otherwise. *Debt-Ratio* equals the ratio of total debt to total assets.

Table 2: Frontier Estimates of Translog Cost Function using Data from 1995 to 1998

Asset Equals Output					Revenue Equals Output				
	Simple Model		Complex Model			Simple Model		Complex Model	
Variable	**Coefficient**	**t-ratio**	**Coefficient**	**t-ratio**	**Variable**	**Coefficient**	**t-ratio**	**Coefficient**	**t-ratio**
Constant_1	-0.4742	-0.55	-6.2649*	-7.53	***Constant_1***	0.3250	1.08	-1.2189*	-4.13
lnAsset	0.5560*	4.11	1.2764*	9.74	***lnRevenue***	0.7654*	13.67	0.9887*	18.62
lnAsset*lnAsset	0.0156*	2.87	-0.0074	-1.44	***lnRevenue*lnRevenue***	0.0106*	4.01	0.0023	0.92
ln(1+i)			24.2147*	24.41	***ln(1+i)***			7.6817*	4.49
ln(1+i)*ln(1+i)			-13.9607*	-14.05	***ln(1+i)*ln(1+i)***			-3.4289*	-2.96
ln(1+p)			11.9710*	12.55	***ln(1+p)***			5.3002*	8.97
ln(1+p)*ln(1+p)			-6.4275*	-9.26	***ln(1+p)*ln(1+p)***			-2.2816*	-9.44
lnAsset*ln(1+i)			-0.6003*	-11.96	***lnRevenue*ln(1+i)***			-0.2781*	-3.51
lnAsset*ln(1+p)			-0.0336	-0.85	***lnRevenue*ln(1+p)***			-0.0869*	-3.58
ln(1+i)*ln(1+p)			-10.7590*	-10.88	***ln(1+i)*ln(1+p)***			-2.3575*	-3.11
Debt-Ratio	2.0906*	18.15	0.8340*	14.26	***Debt-Ratio***	1.0940*	18.41	0.7195*	17.95
Constant_2	-1.0823	-1.34	-0.0079	-0.39	***Constant_2***	-0.4187	-0.98	-5.0797*	-2.77
Time	-0.3919*	-4.55	-0.0116	-1.37	***Time***	-0.2084*	-3.44	0.4275**	2.09
Self-Managed	1.2119**	2.21	0.0890*	9.04	***Self-Managed***	-0.5505**	-2.54	-0.5459*	-2.70
Debt-Ratio	-10.4725*	-23.27	-0.0087	-0.79	***Debt-Ratio***	-4.3627*	-4.06	-1.3065*	-4.61
Sigma-Squared	2.3247*	7.42	0.0390*	19.73	***Sigma-Squared***	0.5866*	3.49	0.6388*	3.70
Gamma	0.9321*	85.34	0.0013	1.18	***Gamma***	0.9186*	39.56	0.9500*	70.68

Note: See Table 1. We specify the cost frontier as a translog function where the debt-to-asset ratio shifts the intercept. Asset equals total assets and Rev equals total revenue. Sigma-squared (σ^2) equals $\sigma_v^2 + \sigma_u^2$ and gamma equals σ_u^2/σ^2. The simple model excludes input prices, the complex model includes them. The Constant_2 and the variables that follow it refer to the estimates of the inefficiency term; see equation (7).

* significantly different from zero at the 1-percent level.;
** significantly different from zero at the 5-percent level.

Table 3: Frontier Estimates of Translog Cost Function using Data from 1995 to 1999

Asset Equals Output					Revenue Equals Output				
	Simple Model		Complex Model			Simple Model		Complex Model	
Variable	**Coefficient**	**t-ratio**	**Coefficient**	**t-ratio**	**Variable**	**Coefficient**	**t-ratio**	**Coefficient**	**t-ratio**
Constant_1	-0.0182	-0.02	-3.2939*	-6.31	***Constant_1***	1.2743*	5.54	-0.1934	-0.83
lnAsset	0.4729*	3.81	0.9371*	14.65	***lnRevenue***	0.6050*	14.66	0.8471*	19.94
lnAsset*lnAsset	0.0193*	3.97	0.0018	0.55	***lnRevenue*lnRevenue***	0.0178*	9.28	0.0071*	3.53
ln(1+i)			2.9972*	3.06	***ln(1+i)***			1.7027	1.55
ln(1+i)*ln(1+i)			-5.7794*	-5.83	***ln(1+i)*ln(1+i)***			-1.5433**	-1.98
ln(1+p)			6.8453*	6.94	***ln(1+p)***			3.5849*	8.31
ln(1+p)*ln(1+p)			-3.2301*	-52.95	***ln(1+p)*ln(1+p)***			-1.0245*	-7.72
lnAsset*ln(1+i)			0.1578*	2.81	***lnRevenue*ln(1+i)***			-0.0237	-0.42
lnAsset*ln(1+p)			0.0499	1.35	***lnRevenue*ln(1+p)***			-0.0614*	-3.25
ln(1+i)*ln(1+p)			-2.0131**	-2.04	***ln(1+i)*ln(1+p)***			0.3151	0.43
Debt-Ratio	2.0387*	19.94	0.9461*	15.83	***Debt-Ratio***	0.9491*	21.24	0.7635*	17.89
Constant_2	-1.8987*	-3.76	-0.0186	-0.63	***Constant_2***	-3.0645*	-2.61	-4.6126*	-4.09
Time	0.1389	1.78	-0.0048	-1.56	***Time***	-0.2638*	-5.20	0.2518*	4.14
Self-Managed	1.3548*	3.75	0.1100**	2.39	***Self-Managed***	-0.2200	-0.54	0.0379	0.50
Debt-Ratio	-10.5132*	-10.24	-0.0444	-0.71	***Debt-Ratio***	-3.2843*	-4.58	-1.5865*	-6.10
Sigma-Squared	2.2436*	6.42	0.0528*	28.03	***Sigma-Squared***	0.9053*	4.86	0.5457*	4.70
Gamma	0.9286*	65.34	0.0068*	0.86	***Gamma***	0.9545*	99.13	0.9390*	72.60

Note: See Table 1. We specify the cost frontier as a translog function where the debt-to-asset ratio shifts the intercept. Asset equals total assets and Rev equals total revenue. Sigma-squared (σ^2) equals $\sigma_v^2 + \sigma_u^2$ and gamma equals σ_u^2/σ^2. The simple model excludes input prices, the complex model includes them. The Constant_2 and the variables that follow it refer to the estimates of the inefficiency term; see equation (7).

** significantly different from zero at the 1-percent level.
** significantly different from zero at the 5-percent level.

Table 4: Frontier Estimates of Translog Cost Function using Data from 1995 to 2000

Asset Equals Output					Revenue Equals Output				
	Simple Model		Complex Model			Simple Model		Complex Model	
Variable	**Coefficient**	**t-ratio**	**Coefficient**	**t-ratio**	**Variable**	**Coefficient**	**t-ratio**	**Coefficient**	**t-ratio**
Constant_1	-0.2806	-0.44	-3.6917*	-9.16	***Constant_1***	1.1746*	31.71	0.5864*	3.03
lnAsset	0.5056*	4.91	0.9888*	16.38	***lnRevenue***	0.6191*	34.18	0.7262*	20.91
lnAsset*lnAsset	0.0183*	4.45	0.0003	0.13	***lnRevenue*lnRevenue***	0.0171*	16.27	0.0116*	7.08
ln(1+i)			4.8582*	4.99	***ln(1+i)***			-1.1394	-1.08
ln(1+i)*ln(1+i)			-5.3034*	-7.45	***ln(1+i)*ln(1+i)***			-0.9609	-1.46
ln(1+p)			7.3886*	11.86	***ln(1+p)***			3.6376*	10.97
ln(1+p)*ln(1+p)			-3.0603*	-35.86	***ln(1+p)*ln(1+p)***			-0.8204*	-7.64
lnAsset*ln(1+i)			0.0822**	2.25	***lnRevenue*ln(1+i)***			0.1047**	2.00
lnAsset*ln(1+p)			0.0231	1.01	***lnRevenue*ln(1+p)***			-0.0710*	-4.82
ln(1+i)*ln(1+p)			-2.8554*	-4.48	***ln(1+i)*ln(1+p)***			-0.0605	-0.11
Debt-Ratio	2.0413*	19.75	0.9527*	60.29	***Debt-Ratio***	1.0117*	27.44	0.7767*	35.36
Constant_2	-2.1866*	-3.92	-0.0250	-0.48	***Constant_2***	-1.7772	-1.43	-5.2823*	-10.32
Time	0.2903*	6.17	-0.0043	-0.78	***Time***	-0.0581	-0.92	0.1551*	12.59
Self-Managed	1.5030*	8.93	0.1266*	6.68	***Self-Managed***	0.0632	0.34	0.5522*	7.00
Debt-Ratio	-10.2811*	-26.81	-0.0603	-0.98	***Debt-Ratio***	-4.6382**	-2.46	-0.9152*	-6.94
Sigma-Squared	2.1761*	11.31	0.0466*	18.46	***Sigma-Squared***	0.7044*	2.71	0.5659*	12.59
Gamma	0.9292*	141.01	0.0063	0.14	***Gamma***	0.9469*	81.58	0.9432*	202.29

Note: See Table 1. We specify the cost frontier as a translog function where the debt-to-asset ratio shifts the intercept. Asset equals total assets and Rev equals total revenue. Sigma-squared (σ^2) equals $\sigma_v^2 + \sigma_u^2$ and gamma equals σ_u^2/σ^2. The simple model excludes input prices, the complex model includes them. The Constant_2 and the variables that follow it refer to the estimates of the inefficiency term; see equation (7).

* significantly different from zero at the 1-percent level.
** significantly different from zero at the 5-percent level.

Table 5: Frontier Estimates of Translog Cost Function using Data from 1995 to 2001

Asset Equals Output					Revenue Equals Output				
	Simple Model		Complex Model			Simple Model		Complex Model	
Variable	**Coefficient**	**t-ratio**	**Coefficient**	**t-ratio**	**Variable**	**Coefficient**	**t-ratio**	**Coefficient**	**t-ratio**
Constant_1	-0.7477	-1.12	-3.6350*	-11.60	***Constant_1***	0.9870*	4.77	0.3580	1.63
lnAsset	0.5717*	5.58	0.9629*	20.76	***lnRevenue***	0.6582*	17.65	0.7640*	19.94
lnAsset*lnAsset	0.0160*	4.04	0.0018	1.02	***lnRevenue*lnRevenue***	0.0153*	8.92	0.0104*	6.08
ln(1+i)			7.4872*	7.52	***ln(1+i)***			0.3319	0.32
ln(1+i)*ln(1+i)			-4.9699*	-16.37	***ln(1+i)*ln(1+i)***			-0.9809*	-3.13
ln(1+p)			7.3628*	17.55	***ln(1+p)***			3.6432*	10.88
ln(1+p)*ln(1+p)			-2.9385*	-39.47	***ln(1+p)*ln(1+p)***			-0.8179*	-8.02
lnAsset*ln(1+i)			-0.0175	-0.44	***lnRevenue*ln(1+i)***			0.0364	0.73
lnAsset*ln(1+p)			0.0178	1.13	***lnRevenue*ln(1+p)***			-0.0725*	-4.85
ln(1+i)*ln(1+p)			-3.9826*	-10.26	***ln(1+i)*ln(1+p)***			-0.1016	-0.27
Debt-Ratio	2.0549*	23.46	1.0173*	27.75	***Debt-Ratio***	0.9883*	22.18	0.7245*	19.60
Constant_2	-2.1741*	-4.64	0.0386**	2.02	***Constant_2***	-2.8946*	-4.47	-6.0659*	-7.26
Time	0.3572*	8.92	-0.0017	-0.76	***Time***	0.2209*	6.14	0.3434*	8.97
Self-Managed	1.2663*	4.26	0.1083*	6.34	***Self-Managed***	-0.1681*	-2.76	-0.2732*	-5.04
Debt-Ratio	-10.4681*	-13.43	-0.1438*	-4.15	***Debt-Ratio***	-4.5812*	-7.10	-0.2485	-1.32
Sigma-Squared	2.1957*	10.28	0.0469*	30.04	***Sigma-Squared***	0.7760*	6.30	0.6033*	9.06
Gamma	0.9324*	100.13	0.0025*	3.27	***Gamma***	0.9546*	129.93	0.9501*	121.82

Note: See Table 1. We specify the cost frontier as a translog function where the debt-to-asset ratio shifts the intercept. Asset equals total assets and Rev equals total revenue. Sigma-squared (σ^2) equals $\sigma_v^2 + \sigma_u^2$ and gamma equals σ_u^2/σ^2. The simple model excludes input prices, the complex model includes them. The Constant_2 and the variables that follow it refer to the estimates of the inefficiency term; see equation (7).

* significantly different from zero at the 1-percent level.

** significantly different from zero at the 5-percent level.

Table 6: Frontier Estimates of Translog Cost Function using Data from 1995 to 2002

Asset Equals Output					Revenue Equals Output				
	Simple Model		Complex Model			Simple Model		Complex Model	
Variable	**Coefficient**	**t-ratio**	**Coefficient**	**t-ratio**	**Variable**	**Coefficient**	**t-ratio**	**Coefficient**	**t-ratio**
Constant_1	-1.0151	-1.56	-4.1548*	-13.77	***Constant_1***	0.7803*	4.88	0.4446*	3.62
lnAsset	0.6098*	6.10	1.0256*	22.80	***lnRevenue***	0.6936*	23.18	0.7491*	31.97
lnAsset*lnAsset	0.0148*	3.81	0.0001	0.08	***lnRevenue*lnRevenue***	0.0138*	9.84	0.0109*	9.67
ln(1+i)			9.7692*	9.88	***ln(1+i)***			-0.5412	-0.56
ln(1+i)*ln(1+i)			-5.2861*	-16.43	***ln(1+i)*ln(1+i)***			-0.9795*	-3.07
ln(1+p)			7.8270*	18.86	***ln(1+p)***			4.0188*	12.39
ln(1+p)*ln(1+p)			-2.9764*	-39.57	***ln(1+p)*ln(1+p)***			-0.7419*	-7.61
lnAsset*ln(1+i)			-0.0889**	-2.26	***lnRevenue*ln(1+i)***			0.0746	1.57
lnAsset*ln(1+p)			0.0039	0.25	***lnRevenue*ln(1+p)***			-0.0911*	-6.34
ln(1+i)*ln(1+p)			-4.6265*	-11.75	***ln(1+i)*ln(1+p)***			-0.1013	-0.26
Debt-Ratio	2.0383*	25.17	0.9160*	25.92	***Debt-Ratio***	0.9666*	23.69	0.7543*	19.74
Constant_2	-2.0624*	-7.11	-0.0697**	-2.10	***Constant_2***	-3.2694*	-5.40	-2.7253*	-9.96
Time	0.3171*	13.94	-0.0041	-1.39	***Time***	0.2251*	12.11	0.2624*	12.70
Self-Managed	0.8268*	4.14	0.2047*	6.24	***Self-Managed***	-0.8689*	-4.73	-0.6999*	-10.17
Debt-Ratio	-11.4805*	-16.48	-0.0824*	-2.76	***Debt-Ratio***	-4.3014*	-12.05	-1.8409*	-10.26
Sigma-Squared	2.5368*	10.02	0.0525*	27.93	***Sigma-Squared***	0.9535*	8.30	0.3801*	13.89
Gamma	0.9370*	111.35	0.0086*	2.63	***Gamma***	0.9648*	198.84	0.9204*	108.83

Note: See Table 1. We specify the cost frontier as a translog function where the debt-to-asset ratio shifts the intercept. Asset equals total assets and Rev equals total revenue. Sigma-squared (σ^2) equals $\sigma_v^2 + \sigma_u^2$ and gamma equals σ_u^2/σ^2. The simple model excludes input prices, the complex model includes them. The Constant_2 and the variables that follow it refer to the estimates of the inefficiency term; see equation (7).

* significantly different from zero at the 1-percent level.
** significantly different from zero at the 5-percent level.

Table 7: Frontier Estimates of Translog Cost Function using Data from 1995 to 2003

Asset Equals Output					Revenue Equals Output				
	Simple Model		Complex Model			Simple Model		Complex Model	
Variable	**Coefficient**	**t-ratio**	**Coefficient**	**t-ratio**	**Variable**	**Coefficient**	**t-ratio**	**Coefficient**	**t-ratio**
Constant_1	-1.1090	-1.54	-4.0884*	-15.52	***Constant_1***	0.7428*	5.39	0.5517*	3.30
lnAsset	0.6217*	5.63	1.0166*	26.88	***lnRevenue***	0.6981*	28.89	0.7324*	24.95
lnAsset*lnAsset	0.0143*	3.33	0.0005	0.39	***lnRevenue*lnRevenue***	0.0136*	12.31	0.0117*	8.81
ln(1+i)			10.1945*	10.37	***ln(1+i)***			-0.7977	-0.82
ln(1+i)*ln(1+i)			-5.3714*	-17.22	***ln(1+i)*ln(1+i)***			-0.8953*	-2.83
ln(1+p)			7.5172*	19.29	***ln(1+p)***			3.9660*	12.53
ln(1+p)*ln(1+p)			-2.9532*	-42.84	***ln(1+p)*ln(1+p)***			-0.7443*	-8.09
lnAsset*ln(1+i)			-0.1027*	-2.62	***lnRevenue*ln(1+i)***			0.0805	1.75
lnAsset*ln(1+p)			0.0129	0.88	***lnRevenue*ln(1+p)***			-0.0916*	-6.61
ln(1+i)*ln(1+p)			-4.6010*	-13.30	***ln(1+i)*ln(1+p)***			0.0327	0.09
Debt-Ratio	2.0825*	29.41	0.9097*	32.54	***Debt-Ratio***	0.9819*	30.13	0.7344*	23.90
Constant_2	-1.6301*	-5.27	0.0148	0.56	***Constant_2***	-2.3940*	-4.49	-2.8996*	-8.17
Time	0.2886*	13.47	-0.0055*	-5.70	***Time***	0.1490*	5.07	0.2006*	10.92
Self-Managed	0.5978*	3.59	0.1068*	2.68	***Self-Managed***	-0.7536*	-10.19	-0.8617*	-10.83
Debt-Ratio	-11.5772*	-34.08	-0.0716*	-4.41	***Debt-Ratio***	-4.9426*	-20.58	-1.8687*	-8.87
Sigma-Squared	2.4366*	16.49	0.0509*	30.10	***Sigma-Squared***	0.8796*	8.02	0.4430*	10.63
Gamma	0.9368*	173.46	0.0019	1.80	***Gamma***	0.9621*	197.33	0.9332*	130.70

Note: See Table 1. We specify the cost frontier as a translog function where the debt-to-asset ratio shifts the intercept. Asset equals total assets and Rev equals total revenue. Sigma-squared (σ^2) equals $\sigma_v^2 + \sigma_u^2$ and gamma equals σ_u^2/σ^2. The simple model excludes input prices, the complex model includes them. The Constant_2 and the variables that follow it refer to the estimates of the inefficiency term; see equation (7).

* significantly different from zero at the 1-percent level.
** significantly different from zero at the 5-percent level.

Table 8: Average Economies of Scale

Year	Assets		Revenue	
	Simple	**Complex**	**Simple**	**Complex**
1998 (236)	0.9723	1.0426	1.0060	1.0173
1999 (233)	0.9892	1.0013	1.0142	1.0020
2000 (220)	0.9991	1.0054	1.0176	0.9957
2001 (208)	1.0039	1.0124**	1.0159	1.0018
2002 (198)	1.0119	1.0234*	1.0161	0.9976
2003 (132)	1.0288	1.0266*	1.0362	1.0166
Total (1,227)	0.9982	1.0181	1.0162	1.0046

Note: The numbers report the average economies of scale measure for REITs in each year based on Assets and Revenue as output and using the simple (no input prices included in the translog specification) and complex (including input prices models in the translog specification). Total measures the average across all six years. Numbers in parentheses equal the number of REITs.

* means significantly different from one at the 1-percent level in a two-tailed test.

** means significantly different from one at the 5-percent level in a two-tailed test.

Table 9: Average Efficiency

Year	Assets		Revenue	
	Simple	**Complex**	**Simple**	**Complex**
1998 (236)	1.6836	1.0240	1.1669	1.1512
1999 (233)	2.1885	1.0367	1.1680	1.1353
2000 (220)	2.1751	1.0366	1.1802	1.1318
2001 (208)	2.0271	1.0485	1.2644	1.1713
2002 (198)	1.8363	1.0478	1.2938	1.1805
2003 (132)	2.2358	1.0317	1.2005	1.1331
Total (1,227)	2.0099	1.0375	1.2102	1.1509

Note: The numbers report the average efficiency measure for REITs in each year based on Assets and Revenue as output and using the simple (no input prices included in the translog specification) and complex (including input prices models in the translog specification). Total measures the average across all six years. Numbers in parentheses equal the number of REITs.