Green Buildings

Exploring performance and thresholds

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Abstract

The overall aim of this research project is to study green/energy-efficient real estate from an economic perspective. The thesis summarizes the results from five different studies with a connection to green/energy-efficient real estate. These studies focus on three distinguishable research questions: “Do green buildings have a superior indoor environment?”, “Does energy efficiency add value?”, and “What prevents profitable energy-efficiency measures from being undertaken?” Paper A studies the first research question, papers B and C focus on the second research question, and papers D and E examine the third research question.

The aim of the first paper (paper A) is to study how tenants perceive the indoor environment in green-rated premises, and to compare these results with tenants’ perception of a conventional building’s indoor environment. This paper studies two buildings, a LEED-certified building and a conventional building. The main result is that the tenants in the green-rated building are more satisfied with the indoor environment than the tenants in the conventional building.

Papers B and C assess whether energy efficiency has an impact on buildings’ income and market values using Swedish real-estate data. The key result is that although there is a small impact on building-related income, this does not seem to translate into a higher market value. This result is probably due to the value premium being too small or to the real-estate appraiser not putting an emphasis on energy efficiency when appraising real estate.

The last two papers included in this thesis study hindrances to a more energy-efficient building sector. In paper D, two office buildings are used as baseline cases to provide insights into the difficulties that can arise when trying to upgrade a building to make it more energy efficient. The results indicate that changing existing leases is a prohibitive process and that it is often difficult to evaluate the final impact of an energy upgrade. The last paper focuses on why it may be rational to postpone green refurbishments even if they are profitable. This purpose is accomplished by applying the real options analyses (ROA) framework on a simulated case, using Swedish data. The main result is that it may be rational to postpone such refurbishments. However, by introducing different financial penalties and/or subsidies, these investments could be triggered today. Such policies must be carefully outlined in order to prevent the creation of any misplaced incentives.

To sum up, the results indicate that green buildings are preferred by tenants, but that there still appear to be economic barriers to a greener building sector.

Keywords: Green Buildings, Energy-Efficient Buildings, EPC, Indoor Environment Quality (IEQ), Real Options Analyses (ROA), Real-Estate Economics

Sammanfattning

Det övergripande syftet med denna avhandling är att studera grön/energieffektiva byggnader ur ett ekonomiskt perspektiv. Avhandlingen består av en kappa och fem separata studier, vilka belyser tre olika forskningsfrågor.

Syftet med den första studien är att studera hur hyresgäster upplever inomhusmiljön i gröna byggnader. I studien jämförs inomhusmiljön i en grön byggnad med inomhusmiljön i en likvärdig konventionell byggnad. Resultatet visar, på det stora hela, att hyresgästerna är mer nöjda med inomhusmiljön i den gröna byggnaden. De nästföljande studierna, B respektive C, undersöker om byggnadens energiprestanda har någon inverkan på dess hyra respektive marknadsvärde. Resultaten visar på en liten signifikant hyrespåverkan, dock verkar denna inte ha någon effekt på byggnadernas marknadsvärdebedömningar. Skälet till detta kan vara att hyrespremien anses för liten för att ha någon signifikant inverkan på byggnadens marknadsvärde, alternativt att fastighetsvärderare inte beaktar energiprestanda när en fastighet värderas.

De två sista studierna studerar varför vissa, tillsynes lönsamma, energiinvesteringar inte genomförs. Resultaten från studie D visar på svårigheterna med att ingå ett samarbetsavtal (för att eliminera felaktiga incitament) mellan hyresgäst och hyresvärd. Sådana avtal tar lång tid att förhandla fram och det uppkommer ofta svårigheter med att utvärdera de tänkta energiinvesteringarnas ekonomiska utfall. Studie E utgår ifrån en realoptionsmodell, vilken används för att utvärdera när ”gröna” renoveringar bör genomföras i en befintlig byggnad. Studien visar att det kan vara rationellt att vänta trots att investeringen idag är lönsam. Vidare visar resultaten att det är möjligt att via byggsubventioner/finansiella ”straff” påverka aktörer att tidigarelägga energieffektiviseringsåtgärder. Dock är det viktigt att dessa utformas korrekt så att det inte skapar några snedvridna incitament.

Övergripande visar resultaten att gröna byggnader är att föredra ur ett brukarperspektiv men att det fortfarande finns ekonomiska hinder för en mer hållbar byggsektor.

Nyckelord: gröna byggnader, energieffektiva byggnader, EPC, inomhusmiljö, Realoptioner, fastighetsekonomi.

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List of appended papers

Paper A

Magnus Bonde & Jill Ramirez (2015) "A post-occupancy evaluation of a green rated and conventional on-campus residence hall", *International Journal of Sustainable Built Environment,* Vol. 4 No. 2, pp. 400–408

Paper B

Magnus Bonde & Han-Suck Song (2013) "Does greater energy performance have an impact on real estate revenues?", *Journal of Sustainable Real Estate*, Vol. 5 No. 1, pp. 174–185

Paper C

Magnus Bonde & Han-Suck Song (2013) "Is energy performance capitalized in office building appraisals?", *Property Management*, Vol. 31 No. 3, pp. 200–215
DOI: 10.1108/02637471311321450

Paper D

Magnus Bonde (2012) "Difficulties in changing existing leases—one explanation of the 'energy paradox'?", *Journal of Corporate Real Estate*, Vol. 14 No. 1, pp. 63–76
DOI: http://dx.doi.org/10.1108/14630011211231446

Paper E

Magnus Bonde & Han-Suck Song (2015) "'Green' refurbishments under uncertainty", *Working paper*

Contents

Introduction

The real-estate and construction sector has been identified as an energy-intensive sector, with a global share of 32% of total energy usage. As a result, 19% of global greenhouse gas emissions can be attributed to the sector (Chalmers, 2014; IEA, 2015). In Sweden, 28% of national energy usage and 20% of greenhouse gas emissions can be attributed to the Swedish real-estate and construction sector (Toller et al., 2009). According to Stocker et al. (2013), writing as Working Group I of the Intergovernmental Panel on Climate Change (IPCC) fifth assessment report, greenhouse gas emissions have an effect on global climate, resulting in increasing temperatures, higher sea levels, and shrinking artic sea-ice. However, this process can be mitigated and the real-estate and construction sector can be a great contributor to this endeavor, as energy savings in the range of 50–90% are possible to achieve using today's best practices (Chalmers, 2014).

The "modern-day" green building movement was fueled by the oil crisis in the seventies, which spurred the development of energy-efficient technologies. However, its origin can be traced back to the late nineteenth century and even as far back as the Anasazi American Indian tribe in 700 A.D. (Charles J. Kibert, 2004; USGBC, 2003; Voll, n.d.). During the last decade, a newfound interest in green building design can be observed in the real-estate sector, revealed by the increasing number of green-rated buildings (BRE Global, 2014; Katz, 2012; Kriss, 2014; Stockholms Stad, 2015). However, in order for this interest to endure, there must be an economic benefit. To date, several studies have examined the linkage between green building features (improved energy efficiency, better indoor climate, etc.) and financial factors (rents, market values, transaction prices, etc.) (World Green Building Council, 2013). Still, research within this field in Sweden is fairly limited, although it is increasing with the works of Högberg (2014) and Zalejska-Jonsson (2013).

The aim of this thesis is to study green/energy-efficient buildings and retrofits, mainly from an economic perspective and primarily using Swedish data/cases. The thesis emphasizes three distinguishable research questions: "Do green buildings have a superior indoor environment?" (RQ1), "Does energy efficiency add value?" (RQ2), and "What prevents profitable energy-efficiency measures from being undertaken?" (RQ3). RQ1 is studied in paper A, RQ2 is examined in papers B and C, and RQ3 is studied in papers D and E, as illustrated in Figure 1.

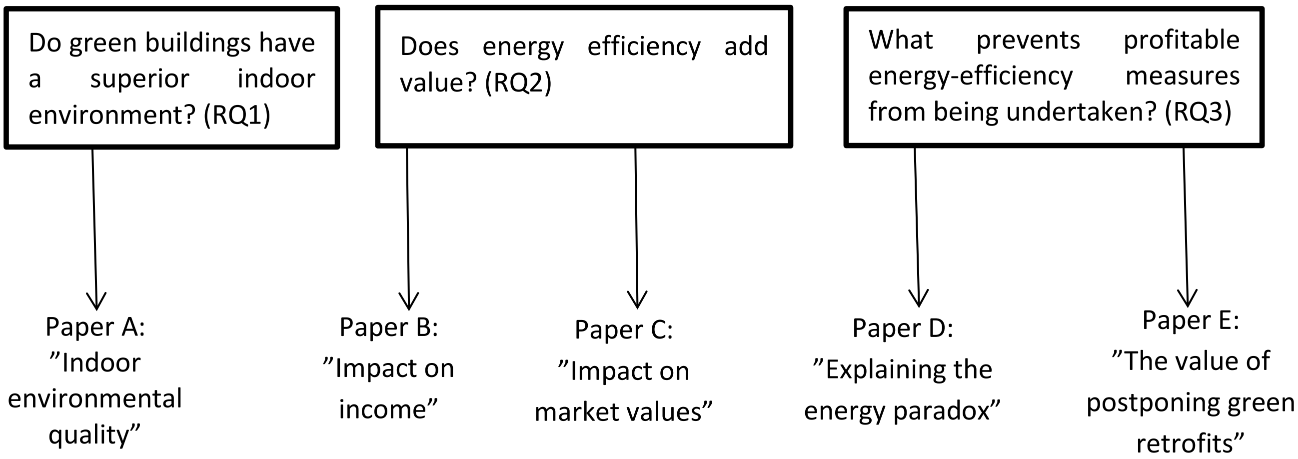


Figure 1: The structure of the thesis

This cover essay is outlined as follows: First, the terminology within this research field is defined; second, the theoretical framework for this thesis is described, followed by an explanation of the applied research methods; and last, an overview of the included papers in the thesis is presented along with the overall research contributions and results.

Definitions

Thus far, no single established definition of a sustainable building exists. However, multiple guidelines and standards have been developed in order to evaluate (and certify) how buildings fulfill certain environmental benchmarks; examples include BREEAM and LEED (Ellison and Brown, 2011). This section describes the different definitions that are often used within this research field.

Green/sustainable buildings

Kibert (2008, p.8) put forward the following definition of a green building: “healthy facilities designed and built in a resource-efficient manner, using ecologically based principles .“ This definition mainly focuses on the environmental impact of the building, and does not involve how the building affects, and interacts with, its surroundings and inhabitants. RICS (2009, p.6) defines a sustainable building as follows: “Sustainable buildings should optimise utility for their owners and occupiers and the wider public, whilst minimising the use of natural resources and presenting low environmental impact, including their impact on biodiversity.” This definition has a wider scope, since it incorporates the end-users’ perceptions and the building’s interaction with its surroundings. This definition is in line with Berardi (2013, p.74), who argues that a sustainable building should not only consider the environmental aspects, but also be “designed and operated to match the appropriate fitness for the use with minimum environmental impact." Cole (1999) argues for the following distinction between green and sustainable building assessment: that a green building assessment focuses on the regional environmental aspects, using conventional building practices as a baseline, while a sustainable building is assessed using pre-defined global sustainable (economic, environmental, and social) targets. However, some argue that the sustainability criteria are impossible to fulfill (Cooper, 1999; Goodland and Daly, 1996; Pearce, 2006; Williams and Millington, 2004).

The terms "green" or "sustainable" are commonly used to signal that a building is built in accordance with a third-party environmental rating scheme, such as that of LEED or BREEAM (Zalejska-Jonsson, 2013), and this is the definition used in this thesis.

Energy-efficient/low-energy buildings

Obviously, the terms "energy-efficient building" or "low-energy building" refer to the building's energy performance. These terms put an emphasis on the building's envelope and its technical installations, underlining thermal insulation, energy-efficient windows, and technical schemes (e.g., a heat-recovery ventilation system, solar panels, etc.). Also, in order to provide good indoor comfort, a proper ventilation scheme must be installed (Krope and Goricanec, 2009; Meier et al., 2002).

With regard to performance levels, Sweden has implemented official definitions of low-energy and very low-energy buildings. A low-energy building is defined as a building that uses 25% less energy for space heating[1] than stipulated in the building code, while a very low-energy building must use 50% less energy for space heating than stipulated in the building code (Zalejska-Jonsson, 2013).

Conventional buildings

A conventional building is a building constructed in accordance with the regular building code in a specific country during a particular time period (Sartori and Hestnes, 2007). The synonym "brown building" is also occasionally used.

[1] Space heating is the energy distributed to the building for operations, heating, cooling, and supplying warm water.

Theoretical Framework

Due to the scope of this thesis, theories from three research fields have been used: neo-classic economic theory regarding market imperfections, (real-estate) valuation theory, and real option theory.

Market imperfections

Within the neo-classic economic framework, the world fundamentally consists of households that seek to maximize their utility, and firms that seek to maximize their profits. Furthermore, it is assumed that these actors are rational and fully informed. As such, they will respond to economic incentives that will bring about an efficient distribution of resources (Jehle and Reny, 2000; SOU, 2008). However, these assumptions have been questioned, for example by Simon (1955, 1959), who highlights the issue of human cognitive limits. This, and other barriers, can hinder profitable energy-efficiency measures from being undertaken."

The notion of an efficiency gap between theory and practice is referred to as the "energy-efficiency gap" or the "energy paradox," and is defined by Golove and Eto (1996, p. 6) as: "the difference between levels of investment in energy efficiency that appear to be cost effective based on engineering-economic analysis and the (lower) levels actually occurring." The discussion below explains the most relevant barriers to energy efficiency in greater detail.

Asymmetric information and transaction costs—In most cases, information is not evenly distributed. As an example, a seller of a commodity may have more knowledge about it than the buyer, which the buyer is aware of, as presented in Akerlof (1970). Following Akerlof's reasoning regarding the second-hand car market, Schleich (2009) argues that this train of thought can also be applied to building qualities, such as energy efficiency. If a buyer cannot evaluate the building's energy performance (and knows that this information is available for the seller), the buyer will not assess it correctly, and will therefore offer a bid that is too low. Eventually, the result will be that only energy-inefficient buildings are transacted. This asymmetry could be resolved if the seller discloses this information in a trustworthy manner (Schleich, 2009). Using labels and rating schemes such as the (E.U.) Energy Performance Certificate (EPC), LEED, or BREEAM can serve as such a signal (Hirst and Brown, 1990).

Related to the issue of asymmetric information is the notion of *transaction costs*. These costs can consist of time, money, effort, and so forth that add to the price of the commodity (SOU, 2008;

The Swedish National Board of Housing, Building, and Planning, 2005). For energy-efficiency technologies, these costs may be associated with identifying and evaluating energy-efficiency measures, costs for consultants, and so forth. These additional costs add to the investment cost, reducing or even eliminating the profits (Jaffe and Stavins, 1994; Schleich, 2009; The Swedish National Board of Housing, Building, and Planning, 2005).

Split incentives—The term "split incentives" refers to a situation in which two or more actors in an economic exchange do not face the same incentive structure. This barrier is often referred to as the "landlord-tenant dilemma." The setup is as follows: The landlord is responsible for the technical installations, but does not pay the utility bills (a net lease). In this situation, the landlord has an incentive to minimize the capital costs (without any regard to energy efficiency). The tenant, on the other hand, has an incentive to optimize the energy usage of the technical installations, but (often) lacks the ability to undertake any action. This situation brings about an "efficiency" problem, which would be resolved if the landlord paid the utility bills (a gross lease), as he or she could then benefit from improved energy efficiency. On the other hand, in this second setup, the tenant lacks any incentive to optimize the energy usage on the premises, which could result in a "usage" problem. Naturally, the landlord has little or no ability to control the tenant's actions (IEA, 2007; Schleich, 2009; The Swedish National Board of Housing, Building, and Planning, 2005). In theory, this dilemma could be resolved if the participants entered into an agreement that corrected these issues. However, the cost of negotiating such an agreement, as well as verifying the energy cost savings, is often prohibitive (Schleich, 2009).

Bounded rationality—Bounded rationality refers to the limitations of the human cognitive ability. Because humans lack the ability to assimilate all available information, they have to rely on routines and approximations. As such, energy-efficiency investments may be overlooked, even if the incentives are correct and the information is available. For example, firms usually focus on the core production, which may result in even profitable energy-efficiency measures being neglected. In addition, when evaluating energy-efficiency investments, the same discount rates and/or payoff periods are likely to be used (Gillingham and Palmer, 2014; Jones, 1999; Schleich, 2009).

Valuation theory

Four different yet inter-reliant factors fundamentally affect a commodity's monetary value: *utility, scarcity, desire*, and *effective purchasing power (i.e., functioning market)* (Appraisal Institute, 2008).

Utility is related to the ability to meet human needs, wants, and so forth. In a real-estate context, building design, location, technical features, and more can enhance the overall appeal. These characteristics are referred to as *amenities*. A tenant's valuation of amenities can be converted into income in the form of rent. The value of owning real estate derives from the bundle of rights that are associated with it. However, these rights can be restricted by, for example, zoning or environmental regulations, which can detract (or enhance) a property's utility. A commodity's *scarcity* is its supply relative to the current demand. Generally, the scarcity of a commodity makes it more valuable. For a commodity to have a value, it must also satisfy human needs or individual wants, that is, it must be *desirable*. Lastly, a *functioning market* must be in place, in which individuals can participate to exchange goods and services. These factors will influence both the supply and the demand of a property, and will translate into a market price (Appraisal Institute, 2008). The notion of "value" can have many meanings; the meanings that are most relevant for this thesis are elaborated below.

Market value—Numerous definitions of market value exist. The following definition includes the most widely accepted concepts [emphasis added]: "**The most probable price**, as of a specified date, in cash, or in terms equivalent to cash, or in other precisely revealed terms, for which the specified property rights should sell after reasonable exposure in a competitive market under all conditions requisite to a fair sale, with the buyer and seller each acting prudently, knowledgeably, and for self-interest, and assuming that neither is under undue duress" (Appraisal Institute, 2008, p. 23). Thus, a market valuation can be regarded as an objective estimation of the exchange price (Appraisal Institute, 2008; Crosby et al., 2000).

Market worth—The market worth of a property is the price that a market actor would/should pay, if that actor is fully informed and using the information in an efficient manner. Market worth is considered to be an objective estimation (Baum et al., 1996; Crosby et al., 2000; Patrick McAllister, n.d.).

Investment value (individual worth)—In contrast to the definitions above, the investment value is a subjective value. This value is related to a specific investor/group of investors, and how they assess the building amenities. As such, this value may differ from the *market value* of the property. Thus, the investment value is the price an individual actor would bid, if accounting for all available information and acting in an efficient manner (Appraisal Institute, 2008; Meins et al., 2010; Patrick McAllister, n.d.).

The values of real estate reflect four major forces, namely *social forces, economic forces, environmental forces*, and *governmental forces* (Appraisal Institute, 2008).

> *Social forces*—These relate to the demographic composition of the population, such as age and gender distribution, education level, crime rate, and lifestyle options.
>
> *Economic forces*—These relate to the market supply and demand as well as to the population's purchasing power. Studied characteristics include wage levels, employment rates, price levels, new developments, occupancy rates, construction costs, and available mortgage credits.
>
> *Environmental forces*—These consist of human-made as well as natural forces, such as climate, topography, natural barriers (rivers, mountains, etc.), natural surroundings, and primary transportation systems.
>
> *Governmental forces*—These mainly relate to legislation and practices as well as to public services. Examples include public transport, zoning, building and health codes, fiscal policies, rent control, environmental legislation, and legislation related to mortgages (type of loans, loan term, etc.).

These value-influencing forces are all affected by the increasing awareness of and need for a more sustainable development. For example, governmental forces are starting to put emphasis on sustainable development in almost all areas of economic activity. Furthermore, the impact of environmental forces in the form of extreme weather-related phenomena is increasing. In addition, the need for sustainable development and the growing awareness of the benefits of sustainable design are having a larger impact on consumer behavior (Lorenz and Lützkendorf, 2011).

Green Value

The "green value" is defined by Bienert et al. (2010, p. 20) as: "the net additional value obtainable by a green building in the market compared to conventional or non-green properties." This value premium is due to the benefits of sustainable building design, which have an impact on the majority of key input valuation variables (Lorenz and Lützkendorf, 2011; Lützkendorf and Lorenz, 2007). Table 1 illustrates the links between these features and appraisal input variables.

Table 1: Examples of sustainable design features, benefits, and impacts on valuation input parameters

Sustainable design features	Benefits	Impacts
Flexibility and adaptability	Reduction of risks through changes in market participants' preferences (obsolescence) and through restricted usability by third parties (i.e., longer useful economic life and more stable cash flow)	- Rent projection in DCF analyses
Energy efficiency and savings in water usage	Reduction of risks of changes in energy and water prices; improved marketability; reduced business interruption risks (e.g., caused by power outages) through facilities that derive energy from on-site resources and/or have energy-efficiency features	- Operating costs - Rent projection in DCF analyses
High functionality in connection with comfort and health of users and occupants	Reduction of vacancy risks or of losing tenant(s); improved marketability	- Market rent
Construction quality; ease of conducting maintenance, servicing, and recycling activities	Lower repair and maintenance costs; improved marketability	- Operating costs - Market rent

(Lorenz and Lützkendorf, 2008)

Lorenz and Lützkendorf (2008) suggest that sustainable building features such as interior adaptability, energy efficiency, good indoor comfort, and construction quality should impact key valuation input variables such as rent, rent growth, and operating costs. However, as "the quantification of these financial advantages in monetary terms is not yet always possible" (Lorenz and Lützkendorf, 2008, p. 489) in the local market, real-estate appraisers may find it difficult to justify any changes, as suggested above (Lorenz and Lützkendorf, 2008). Nevertheless, in such cases, Lorenz and Lützkendorf (2008), Meins et al. (2010), and Meins and Sager (2015) argue that the characteristics of a green building design affect the property risk, as illustrated in Table 2, implying that future income streams are less risky for sustainable buildings (Lorenz and Lützkendorf, 2011).

Table 2: Links between sustainable design features and reduced property-specific risks (examples)

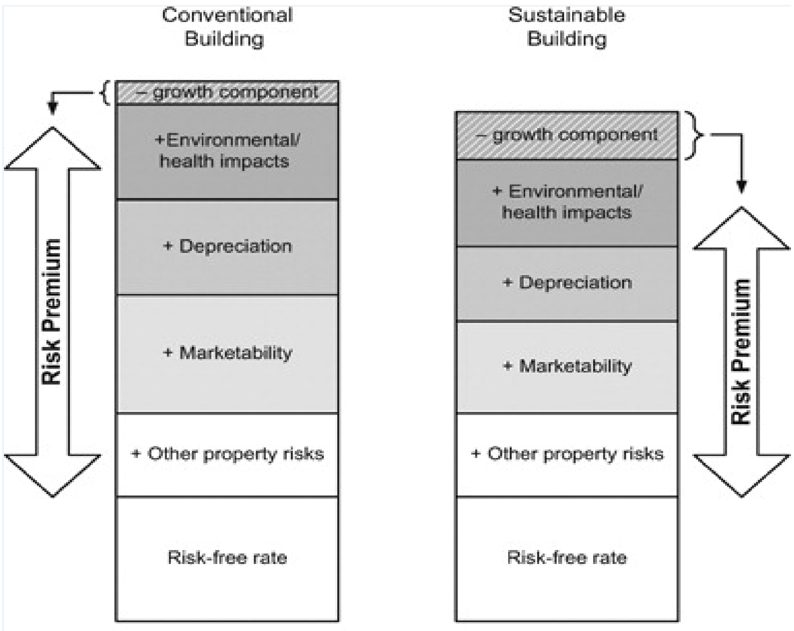
Characteristics and attributes of sustainable buildings	**Examples of reductions in/avoidance of property-specific risks**
Flexibility and adaptability	Reduction of risks in changes in market participants' preferences (obsolescence) and in restricted usability by third parties
Energy efficiency and savings in water usage	Reduction of risks in changes in energy and water prices; reduced business interruption risks (e.g. caused by power outages) through facilities that derive energy from on-site resources and/or have energy-efficiency features
Use of environmentally friendly and healthy building products and materials	Reduction of litigation risks and of being held liable for paying compensation to construction workers and building occupants
High functionality in connection with comfort and health of users and occupants	Reduction of vacancy risks or of losing tenant(s)
Construction quality, systematic maintenance, and market acceptance	Lower risks of changes in property values
Compliance with/over-compliance with legal requirements in the areas of environmental and health protection	Reduction of risks from increasingly stringent legislation (e.g., expensive retrofitting or losses in property values)

(Lorenz and Lützkendorf, 2008)

The aforementioned authors argue that characteristics such as improved construction quality, energy efficiency, adaptability, and over-compliance with the building code reduce the risks of depreciation, changes in energy prices, vacancies, and possible future litigation. In addition, Lorenz and Lützkendorf (2011) argue that sustainable design will become more essential in the future, implying greater value growth. These characteristics should also reduce the property risk premium (illustrated in Figure 2), thereby reducing the discount/capitalization rate used when valuing the property.

However, as a final note, Lorenz and Lützkendorf (2011, p. 659) state that when appraising real estate, "the practitioner's qualitative judgement will ultimately determine the final value of key input parameters."

Figure 2: Impacts on risk premium



(Lorenz and Lützkendorf, 2011)

Real option theory

Income approaches, such as the net present value (NPV) approach, are common procedures when assessing real-estate investments. However, when used to assess investment opportunities, the NPV technique assumes a passive management strategy, and also has the characteristic of a "now-or-never" deal. As such, it fails to address the value of embedded investment opportunities and future managerial flexibilities, often referred to as real[2] options. An option can be defined as "the right **without obligation** to obtain something of value upon the payment or giving up something else of value." (Geltner et al., 2006, p. 730). These options can be assessed using the real options analyses (ROA) framework. A real option is an *irreversible investment under uncertainty* (Dixit and Pindyck, 1994), which has similarities to a perpetual American option[3] (Titman and Martin, 2008). The ROA framework allows a manager to adapt his or her behavior to future events that may add value to the investment. However, ROA should not be regarded as a replacement for the NPV approach; rather, it should be seen as an amendment to the NPV approach (Armerin and Song, 2014; Brealey et al., 2006; Souza et al., 2009).

[2] The term "real" refers to the fact that the underlying asset is a real asset (i.e., physical capital).
[3] An American option is an option that can be exercised at any given time (Titman and Martin, 2008)

Real options can be divided into two categories: options in the pre-investment stage and options in the post-investment stage (Titman and Martin, 2008).

Pre-investment options

In this stage the firm mainly focuses on investment timing and design-for-flexibility. Examples of pre-investment options are:

Staged-investment options—These refer to the fact that one investment opens up the opportunity for further investments. For example, a real-estate developer who acquires an empty plot of land has the option to develop it at a later stage. Similarly, a pharmaceutical company that invests in research has the option to develop and market a new drug (Titman and Martin, 2008).

Timing options ("wait and see" options)—The option to postpone can be beneficial when the uncertainty regarding an investment will, to some extent, be reduced in the future (Geltner, 1989; McDonald and Siegel, 1986; Samuelson and McKean, 1965; Titman, 1985; Titman and Martin, 2008).

Post-investment options

In this stage the firm instead focuses on so called *operational issues*, which may add value to the underlying investment. Examples of post-investment options are:

Growth options—These refer to both the options of growth in scale (increases in production output) and expansion in scope (additional investments made to the original investment) (Titman and Martin, 2008).

Shutdown/abandonment options—These refer to the option to (temporarily) shut down businesses when the economy is in a recession (Titman and Martin, 2008).

Switching options (inputs and outputs)—The option to shift inputs in production can be used to minimize costs; an example is a power generator that can use either oil or natural gas. The option to switch output provides greater managerial flexibility; an example is a textile plant that adapts its production as the demand for different textile goods changes (Brealey et al., 2011; Titman and Martin, 2008).

Research methods and results

This thesis applies multiple research methods to answer the three research questions identified earlier. The papers can be categorized as explanatory, descriptive, or improving studies (Maxwell and Mittapalli, 2008; Runeson and Höst, 2009). An advantage of such an approach is that it allows the scholar to study a greater array of research questions, from both a micro and macro perspective (Creswell and Plano Clark, 2011; Johnson and Onwuegbuzie, 2004). Figure 3 illustrates the research questions studied and the research methods applied in this thesis, while table 3 illustrates the data source.

Table 3: An overview of data source

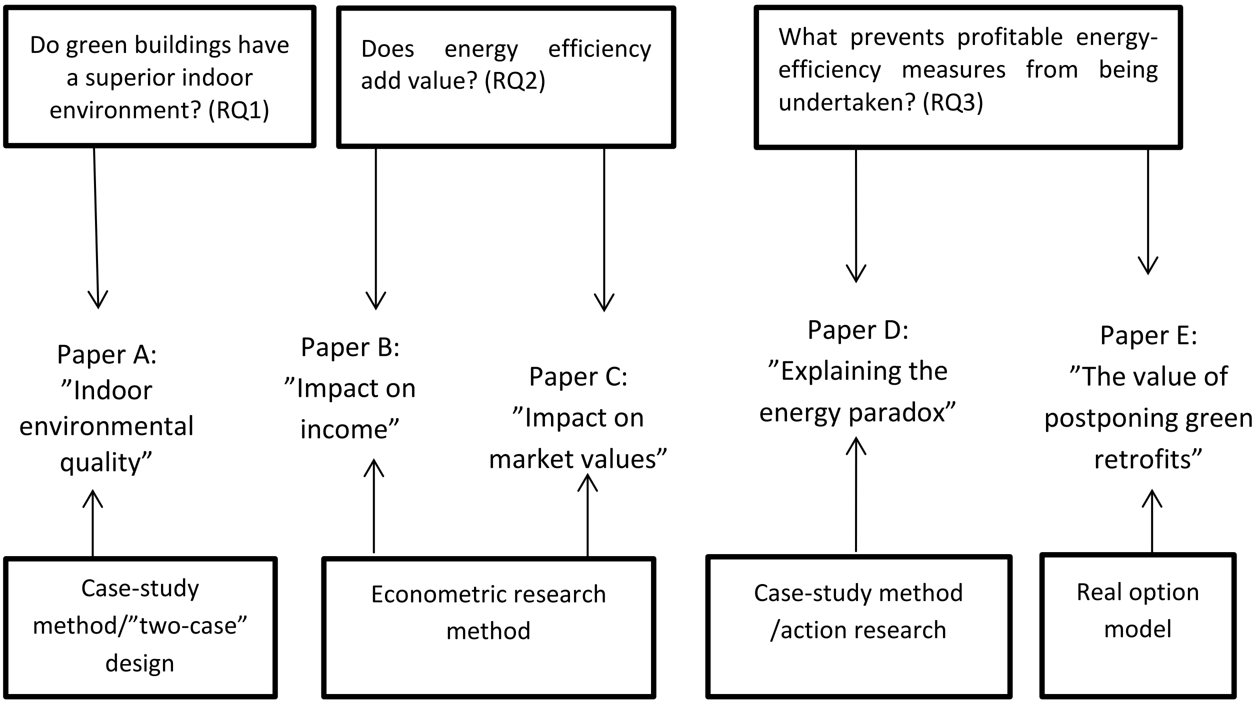
	Interviews	Questionnaire	Observation	Participation	Document study	IPD*
Paper A	(√)	√	(√)		(√)	
Paper B						√
Paper C						√
Paper D	√		√	√	√	
Paper E						√

√ = Primary data source

(√) = Secondary data source

* = Investment Property Databank

Figure 3: An outline of the questions, papers, and applied methods in this thesis.



Paper A

Paper A studies how tenants perceive the indoor environment in a green-rated building. Such perceptions are essential, because if tenants do not appreciate the “green amenities” of a building, they will not be willing to pay any premium for renting such premises. In order to study tenant appreciation of green-rated buildings, we chose to conduct a case study using a qualitative research approach (Flick, 2009) to gather the necessary data. The case study was outlined as a “two-case” (holistic) study, in which two buildings (cases) were chosen (one LEED-rated and one conventional). Data was gathered via interviews and a major survey.

Similar post-occupancy evaluations (POEs), using a case-study method, have been conducted with varied results. Regarding air quality, Abbaszadeh et al. (2006), Gou et al. (2012a), and Zalejska-Jonsson (2012) show that green building occupants are generally more content. Under certain conditions, the same applies to thermal comfort (Abbaszadeh et al., 2006; Gou et al., 2012a, 2012b; Thatcher and Milner, 2012). However, the findings from Gou et al. (2012a, 2012b) and Paul and Taylor (2008) suggest that tenants in green buildings are less satisfied with the thermal comfort. Results also vary regarding lighting qualities; some studies do not find any significant difference between tenant satisfaction with lighting in green versus conventional buildings

(Abbaszadeh et al., 2006; Paul and Taylor, 2008), while others indicate that the occupants of green buildings are less satisfied (Gou et al., 2012b; Thatcher and Milner, 2012).

Paper A shows that the occupants of a green-rated building are more satisfied with the indoor air quality and temperature, while no significant difference was found regarding tenant satisfaction with lighting qualities in green-rated versus conventional buildings.

Papers B and C

Papers B and C study the effect of energy efficiency on real estate, focusing on income and market values. The dataset for these studies was provided by the Investment Property Databank (IPD), who merged their real-estate data with the EPCs provided by the Swedish National Board of Housing, Building, and Planning (Boverket). The dataset was then anonymized before being passed on to us. This dataset enabled us to use an econometric research approach, following the works of Court (1939) and Rosen (1974), in which the latter theoretically validated the technique. As we were provided with a panel dataset stretching from 2003–2010, we decided to estimate a panel equation in order to use as much of the provided data as possible.

A panel data equation can be estimated using a random-effects (RE) model or a fixed-effects (FE) model. The main difference is that an FE model controls for the impact of the time-invariant and unobservable factors by means of a fixed effect. As a result, time-invariant variables cannot be estimated by the model. If the key explanatory variable is time-invariant, an RE model must be used to estimate its impact. However, this model cannot control for any unobservable effects (Williams, 2015; Wooldridge, 2006).

Following the work of Greene (2012), we conducted a Hausman test (Hausman, 1978) to help us determine if an FE or RE model should be used. The result indicated that an FE model would be the most appropriate to use. This result presented a problem, as our key explanatory variable (the EPC rating) is time-invariant, and therefore would be omitted by an FE model. However, using the Hausman test to decide on an FE or RE model has been criticized by Bell and Jones (2015) and Clark and Linzer (2012), as the test is “neither a necessary nor a sufficient metric” (Clark and Linzer, 2012, p. 2) to be used as a decision-making tool. Wooldridge (2006) stresses that the main issue is how certain it is that the independent variables are correlated with the unobservable factors. However, Wooldridge (2006) also underlines that if the key explanatory variable is time-invariant, the RE model must be used. This dilemma can also be solved by using the fixed-effect vector decomposition (FEVD) model, as outlined by Plümper and Troeger (2007, 2011), which can estimate a time-invariant variable in an FE setting. However, Breusch et al. (2011a, 2011b) and Greene (2011a, 2011b, 2012) have raised concerns regarding this method. In the studies included in this thesis, we chose to use the FEVD model in Paper B and the RE model in Paper C.

One of the most well-known articles studying the economic payoff for green real estate was conducted by Eichholtz et al. (2010). This study was one of the first to find a relationship between green/energy-efficient buildings and higher rents/sales prices. Fuerst and McAllister (2011a) replicated this study, and found even stronger correlations between green-rated buildings and higher rents/sales prices. Both these studies rely on U.S. real-estate market data. In Europe, Kok and Jennen (2012) studied the EPC rating effect on office rents in the Netherlands. The study concluded that poorer EPC ratings resulted in lower office rents. Fuerst and McAllister (2011b) also studied the effect of EPC ratings, in this case on the U.K. commercial real-estate market, using data from the IPD. However, the authors could not find any significant correlation between EPC ratings and market values, market rents, or yield (cap rate). In Australia, Gabe and Rehm (2014) showed similar results; they did not find any significant premium for more energy-efficient office premises in downtown Sydney. However, the findings by Fuerst et al. (2013) suggest that buildings with higher EPC ratings produce higher rents. Fuerst and van de Wetering (2015) investigated whether tenants are prepared to pay a rent premium to rent space in BREEAM-rated office buildings. The authors concluded that such a premium exists in the U.K., even considering the recent economic downturn.

With regard to residence properties, Aroul and Hansz (2012) found a significant price premium for energy-efficient premises when investigating the real-estate market in the U.S. In the U.K., Fuerst et al. (2015) also found a transaction price premium for properties with higher EPC ratings. Similar results were observed for the domestic markets in Ireland (Hyland et al., 2013; Stanley et al., 2015), Northern Ireland (Davis et al., 2015), the Netherlands (Brounen and Kok, 2011), and Sweden (Högberg, 2011).

Paper B indicates that energy-efficient buildings earn higher incomes, a result that is in line with the findings of Kok and Jennen (2012) and Fuerst et al. (2013). However, the premium is not great. Paper C found no significant correlation between market values and energy efficiency, a result that is similar to the findings of Fuerst and McAllister (2011b) regarding the impact of EPC ratings on U.K. market values. Therefore, even though a small premium is found in Paper B, the results of Paper C show that it is either being ignored or is considered too small to have an impact on real-estate appraisals.

Paper D

Paper D is based on the fact that large energy savings are possible within a built environment (Schleich, 2009; Chalmers, 2014; Pettersson and Göransson, 2008). Golove and Eto (1996) argue that many energy efficiency measures are economically viable, implying that there is an energy-efficiency gap in built environments. An energy-efficiency gap can be defined as "the difference between levels of investment in energy efficiency that appear to be cost effective based on engineering-economic analysis and the (lower) levels actually occurring" (Golove and Eto, 1996, p. 6).

Paper D is based on an energy review that was conducted in two office buildings prior to our study; these two buildings represent our cases in this study, following the "two-case" (holistic) case-study design by Yin (2009). An energy audit had proposed (seemingly profitable) energy-efficiency measures; however, none had been realized. Therefore, our main aim was to study how this situation had arisen and suggest how it could be resolved. This research method is called (participatory) action research, in which the researcher and practitioner work together to take action and create knowledge. In such a setting, the researcher becomes involved and contributes to the practitioner's environment, and the practitioner becomes involved and contributes to the research result. The two distinguishing features of this approach are the central principle of collaboration (instead of passive observation) and the fact that the intent of the project is to take action (Eden and Huxham, 1996; Coughlan and Coghlan, 2002; Kock, 2014). The result does not have to be a practical output; it may very well be a description of what can go wrong (Eden and Huxham, 1996).

Coughlan and Coghlan (2002) describe the action research process as a cycle: First, a pre-step is conducted in order to understand the concept and purpose. Then data is gathered, most often through participatory observation (Kock, 2014). This method consists of reading agreements, conducting interviews, and participating in meetings (Flick, 2009). Thereafter, the researcher acquires feedback and analyzes data, plans the action, and then implements and evaluates the action. Figure 4 illustrates the action research process cycle.

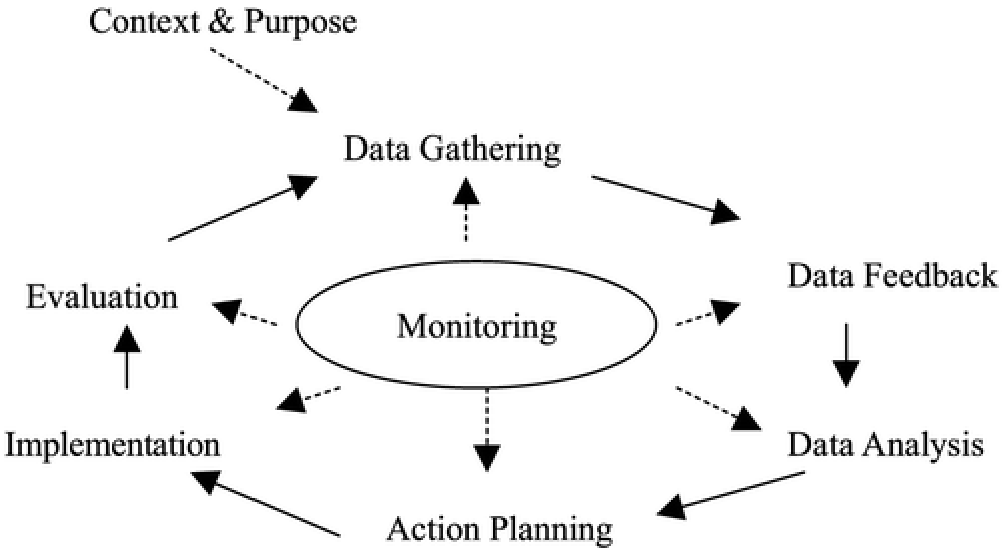


Figure 4: The action research process cycle (Coughlan and Coghlan, 2002).

By the nature of the action research process, it is more or less impossible to replicate action research projects, as every setting is unique. In addition, as the project outputs cannot be foreseen, the truly valuable insights are those that emerge in the research process, and which cannot be obtained in any other way (Coughlan and Coghlan, 2002; Eden and Huxham, 1996).

The final result of our study was that no agreement between the tenant and landlords was reached. The main issues were how to resolve the problems in the lease structure and how to evaluate the financial impact of the energy measures. In addition, the procedure required in order to implement a new agreement was substantial, making the process very costly. Furthermore, the perceptions of what each respective party should do did not make matters easier (e.g., the tenant believed that the landlords should be the one to improve the premises).

Paper E

The traditional technique for assessing investments is to use the NPV criteria; if the present value of the future income stream exceeds or equals the investment cost, the investment should be undertaken (Dixit, 1989). However, this is a static analysis that does not account for future flexibility and the possibility to adapt to new circumstances (Armerin and Song, 2014; Dixit and Pindyck, 1994). Instead, the optimal investment policy should be used to realize an investment when the benefit-cost ratio hits a certain level, often referred to as the investment's "trigger value," in line with the ROA framework (Gunnelin, 2001; McDonald, 1998).

Paper E focuses on the timing (i.e., "wait and see") option: When is the optimal time to commence a green refurbishment in Stockholm Central Business District (CBD)? The methodology stems from the works of McDonald and Siegel (1986) and Samuelson and McKean (1965), and the data was supplied by the IPD, making the input variables very genuine. A special feature in the case of a building refurbishment is that the total investment cost consists of two parts: the current building's value (as this value is "lost") and the refurbishment cost itself (Gunnelin, 2001; Titman and Martin, 2008).

Many researchers have analyzed energy retrofits using a real options approach (e.g., Kumbaroğlu and Madlener, 2012; Lee et al., 2014; van der Maaten, 2010; Menassa, 2011; Hassett and Metcalf, 1993). As illustrated by van Soest and Bulte (2001) and Menassa (2011), the value of the option to defer energy-efficiency investments is larger when the uncertainty is great. Also, when the development (value growth) is rapid, the option value (to postpone) increases, as a better investment can be made in the near future. This behavior has also been observed in the homeowners market (van der Maaten, 2010). Lee et al. (2014) and Menassa (2011) highlight that a multi-stage investment approach could be preferable, as it provides greater managerial flexibility.

Gunnelin (2001) used the ROA to evaluate when to change the usage of a building. As suggested in that study, such refurbishments are triggered when the spread between the respective building usage values are great and refurbishment costs are low.

The base scenario presented in Paper E shows that there is value in postponing green refurbishments, which could explain parts of the energy-efficiency gap in the built environment. However, the study also shows that green refurbishments could be triggered by reducing the refurbishment cost and/or the value of the existing "brown" building. Also, the paper provides a discussion regarding which government interventions could be implemented to reduce the total investment cost (i.e., construction subsides and/or financial penalties).

Reflections on research strengths and limitations

The choice of a research method usually depends on data availability as well as on the specific purpose of the study. However, all research methods have strengths and limitations, as will be discussed in this section. The main strength of this thesis rests on the data acquired for the respective studies, in terms of both its uniqueness and its reliability. The data used in this thesis has either been provided by a trustworthy partner (the IPD) or gathered firsthand. However, when gathering data through interviews and surveys, the phrasing of the questions has an impact on the interviewees' answers. Furthermore, for close-ended questions, the ordering of the answers will affect the answers (Schwarz and Oyserman, 2001; Scheffer, 2013). In addition, as highlighted by Johansson (2009), the researcher's presumptions will have an effect on how the gathered interview data is interpreted; a factor that is often referred to as "inter-observer reliability" (Trochim, 2006). When conducting case studies, some findings will be more general while others may be case specific. However, even if an overall generalization of the results is not possible, the findings can be interpreted as small steps toward an overall generalization (Campbell, 1975).

An issue with the data from the IPD is that it is anonymized, and therefore we cannot control how good of a sample it really is (i.e., one that considers the entire population). In addition, it is difficult for us to control for any errors in the data. Finally, as discussed above, the underlying assumptions behind which model is used will affect the final result.

Overview of papers

Paper A: "A post-occupancy evaluation of a green rated and conventional on-campus residence hall"

Magnus Bonde & Jill Ramirez (2015), *International Journal of Sustainable Built Environment,* Vol. 4 No. 2, pp. 400–408

Introduction

During the last decade, the interest in green building design has increased. However, in order for this positive trend to continue, the outcome of green building design must be evaluated. Such assessment should include the experience of the end-users (i.e., the tenants), in addition to technical and economic assessments.

Purpose and Method

The purpose of this study is to assess the indoor environment in two on-campus resident dorms, one LEED-certified and one conventional building, by conducting a post-occupancy evaluation (POE).

Following Yin (2009), a "two-case" case-study design was arranged. The cases were strategically chosen to be as similar as possible (considering construction/redevelopment date, rent, etc.), with the exception of the green rating. Data was gathered by means of a webbased survey that was sent to all the residents in the two selected buildings. Chi-square tests were used to analyze whether there were any significant differences in the responses.

Key Findings

For performance indicators such as indoor air quality and thermal comfort, the LEED-certified building outperforms the conventional building. However, no significant differences were found for lighting qualities. This result is rather surprising, at least regarding natural light, as the windows in the LEED-certified buildings are larger than those in the conventional building in order to comply with the criteria for "daylight and views" in the LEED-IEQ category.

Paper B: "Does greater energy performance have an impact on real estate revenues?"

Magnus Bonde & Han-Suck Song (2013), *Journal of Sustainable Real Estate*, Vol. 5 No. 1, pp. 174–185

Introduction

In order to mitigate the negative environmental impact from human activities, the European Union has agreed on the so-called "20-20-20" goals (20% reduced greenhouse gas reduction, 20% increased energy efficiency, 20% of all produced energy should be from a renewable source). As a part of this initiative, the directive on the Energy Performance of Buildings was implemented within the E.U., and the directive stipulates that all buildings must undergo a standardized energy assessment (Energy Performance Certificate, EPC).

Purpose and Method

The overall goal is to study whether energy performance (based on the EPC rating) has an impact on office revenues (rents and additional earnings from providing utilities) in Sweden. The data consists of a longitudinal dataset containing real-estate data from the Investment Property Databank (IPD) and EPC data provided by the Swedish National Board of Housing, Building, and Planning (Boverket).

Using the standardized econometric approach, following Court (1939) and Rosen (1974), this study relies on a fixed-effect vector decomposition model (FEVD), as outlined by Plümper and Troeger (2007, 2011), to estimate the EPC's impact. This approach was chosen because it provides us with the opportunity to estimate the impact of a time-invariant explanatory variable within the fixed-effect (FE) model framework.

Key Findings

This study suggests that energy performance has a significant positive impact, albeit a small one, on office income. Further factors that affect office-related revenue are location, costs related to the upkeep of the building, costs associated with heating/cooling, and in what year the lease is signed.

Paper C: "Is energy performance capitalized in office building appraisals?"

Magnus Bonde & Han-Suck Song (2013), *Property Management*, Vol. 31 No. 3, pp. 200–215
DOI: 10.1108/02637471311321450

Introduction

Since Sweden implemented the E.U. directive on the Energy Performance of Buildings, all commercial buildings must undergo an Energy Performance Certification (EPC). The main reason of this certification is to illustrate the building's energy usage in an easily understood and straightforward manner, and thus reduce the information asymmetry.

It is argued that green/energy-efficient buildings bring about higher sales prices/market values. Among others, one argument is that lower utility costs reduce the overall maintenance cost.

Purpose and Method

The aim of this paper is to investigate whether energy performance has an impact on the market values of office buildings in Sweden. The data consists of a longitudinal dataset containing economic data from the Investment Property Databank (IPD) and EPC data provided by the Swedish National Board of Housing, Building, and Planning (Boverket).

This paper uses an econometric approach, which stems from the works of Court (1939) and Rosen (1974). More precisely, a random-effect model is used to estimate the effect of the EPC rating on market values.

Key Findings

This study does not support the notion that greater energy performance (lower energy usage) has an impact on the market values of office premises, indicating that office building appraisers may not be considering EPC ratings. This paper suggests that the main impact factors are rent, the year in which the valuation is conducted, changes in vacancy rates, and location.

Paper D: "Difficulties in changing existing leases—one explanation of the 'energy paradox'?"

Magnus Bonde (2012), *Journal of Corporate Real Estate*, Vol. 14 No. 1, pp. 63–76
DOI: http://dx.doi.org/10.1108/14630011211231446

Introduction

It is argued that there is an "energy-efficiency gap" within the built environment; that is, that profitable energy-efficiency investments are not being fully undertaken by real-estate owners. One explanation, from an economic perspective, is that market failures/barriers hinder such investments. Examples of such failures/barriers include asymmetric information, split incentives, and transaction costs. However, it should be possible for a landlord and tenant to overcome these hindrances by entering into an agreement that could benefit both parties.

Purpose and Method

The purpose of this study is to identify obstacles that hinder energy-efficiency measures within the commercial office building sector in Sweden. In addition, the study has the objective of eliminating these obstacles via an agreement that is beneficial for all stakeholders.

The project has a "two-case" case-study design (Yin, 2009), in which two commercial office buildings in Stockholm are studied. The project has the characteristics of an action research project, as it has the aim both to study and to improve the situation at hand. Data is gathered via participatory observation, which includes an analysis of documents (leases, maintenance agreements), interviews, and direct participation in meetings.

Key Findings

The outcome of this project was that no new agreement was reached. The paper shows that it is difficult and costly to outline an agreement that is acceptable to all involved parties (tenant, landlord, and possible maintenance-operator firm). Furthermore, the landlords were very reluctant to undertake investments with longer payback periods than the length of the lease. As Swedish commercial leases usually have short contract lengths, this myopic view hampers energy-efficiency investments with longer payback periods. The study also revealed that the tenant seemed to be very reluctant to invest in someone else's property. In general, the tenant considered building improvements to be the landlord's responsibility.

Paper E: "'Green' refurbishments under uncertainty"

Magnus Bonde & Han-Suck Song (2015), *Working paper*

Introduction

Traditional investment rules state that an investment should be undertaken if the net present value (NPV) of the benefits exceeds or equals the investment costs. However, this approach is static in the sense that it does not account for future managerial flexibility, which can add value to the investment. This flexibility can be assessed by applying the real options analyses (ROA) framework. This framework provides a method to estimate the optimal time to undertake an (irreversible) investment. As such, it can be a good tool to assess green retrofits within the building sector.

Purpose and Method

The aim of this paper is to estimate the optimal time to undertake the green refurbishment of an existing "brown" building. The paper also discusses how different government interventions could be used to reduce the option value of postponing such investments, and thus trigger these refurbishments.

The paper uses the real option valuation model outlined by McDonald and Siegel (1986) to assess the value of postponing the investment. The necessary data for this study is provided by the Investment Property Databank (IPD).

Key Findings

The base case shows that it is rational to postpone green refurbishments, as flexibility has a positive value. However, if the total retrofit cost were to be reduced, it would trigger green refurbishments of existing buildings today. Therefore, government policies can have an impact on the speed of "greening" the existing building stock. However, these policies have to be carefully arranged to avoid creating any misplaced incentives.

Comment on co-authored papers

The majority of the papers in this thesis were co-authored. In these collaborations, I was involved in the literature review, data collection, modeling, and analysis. I also wrote the major part of the papers.

Contributions and results

The overall purpose of this thesis is to study green/energy-efficient buildings and retrofits. The focus of this research was not to elaborate any new research methodologies, but instead to use already established approaches and theories to study a specific research area, with a focus on the Swedish real-estate sector. Thus, main contribution of this thesis is to add to the growing body of literature within this research field.

To summarize, tenants seem to prefer the indoor environment in green buildings, at least in terms of thermal comfort and air quality. However, there still are some economic barriers toward a more sustainable built environment. First, a premium for improved energy efficiency exists, although it is small; however, it seems that real-estate appraisers do not consider this premium in their property valuations. This is one reason why real-estate owners may be reluctant to go through with energy refurbishments. Second, it is problematic to alter existing leases, and thereby resolve some of the issues with split incentives and similar hindrances. In addition, short/complicated lease structures do not improve the possibility of success. As a result, it can be difficult to acquire the necessary funds to go through with energy refurbishments. It may also be difficult to get the tenant involved in this process, if the tenant considers building improvements to be the landlord's responsibility. Third, even if the incentives are appropriate, it still can be rational to postpone refurbishments, as better investments can be made in the future. As a result, profitable green/energy-efficiency retrofits might not be undertaken.

Nevertheless, these results mainly refer to already existing building stock. For new developments, we observe that most aim for a green rating. This observation indicates that most real-estate developers believe that a green rating will bring about an economic advantage, if not today, then in the near future.[4] Furthermore, by rating a building, a developer may attract a certain kind of investor that prefers such buildings, and as such is prepared to pay a premium. In this case, it can be argued that the investor's investment value (subjective value) is affected by the green rating, although the investment value does not have to be related to the property's market value (objective value).

[4] Unfortunately, this thesis does not study the construction/refurbishment costs for green/energy-efficient buildings. From a developer's point of view, such a study would yield interesting results; however, we were unable to acquire this data.

From a more practical viewpoint, the results of this thesis can be used as input in real-estate companies' business models. For example, companies might use these results when identifying which buildings in a real-estate portfolio to select for a green refurbishment (if any), and when evaluating a good time for this refurbishment to take place. Furthermore, these results can be used when outlining a green lease, to give guidance on which parameters to consider and how to outline the lease in order to minimize the effort of negotiations. It is better to have a generalized agreement than none at all, even if such an agreement results in some refurbishments not being undertaken during the lease term.

Future research

For future research, it would be interesting to elaborate the real option model with regard to construction time lag and uncertain investment costs. It would also be interesting to elaborate a model that considers how other market actors act; that is, to have an approach that is based more on game theory. From my point of view, this elaboration could yield interesting results, as it could, for example, capture first-mover advantage. Continuing to study the impact of green/energy-efficiency labels in other European countries, using an econometric approach, would also be of great interest. Finally, it would be interesting to study how green buildings are monitored over time to maintain the initial/intended performance level.

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