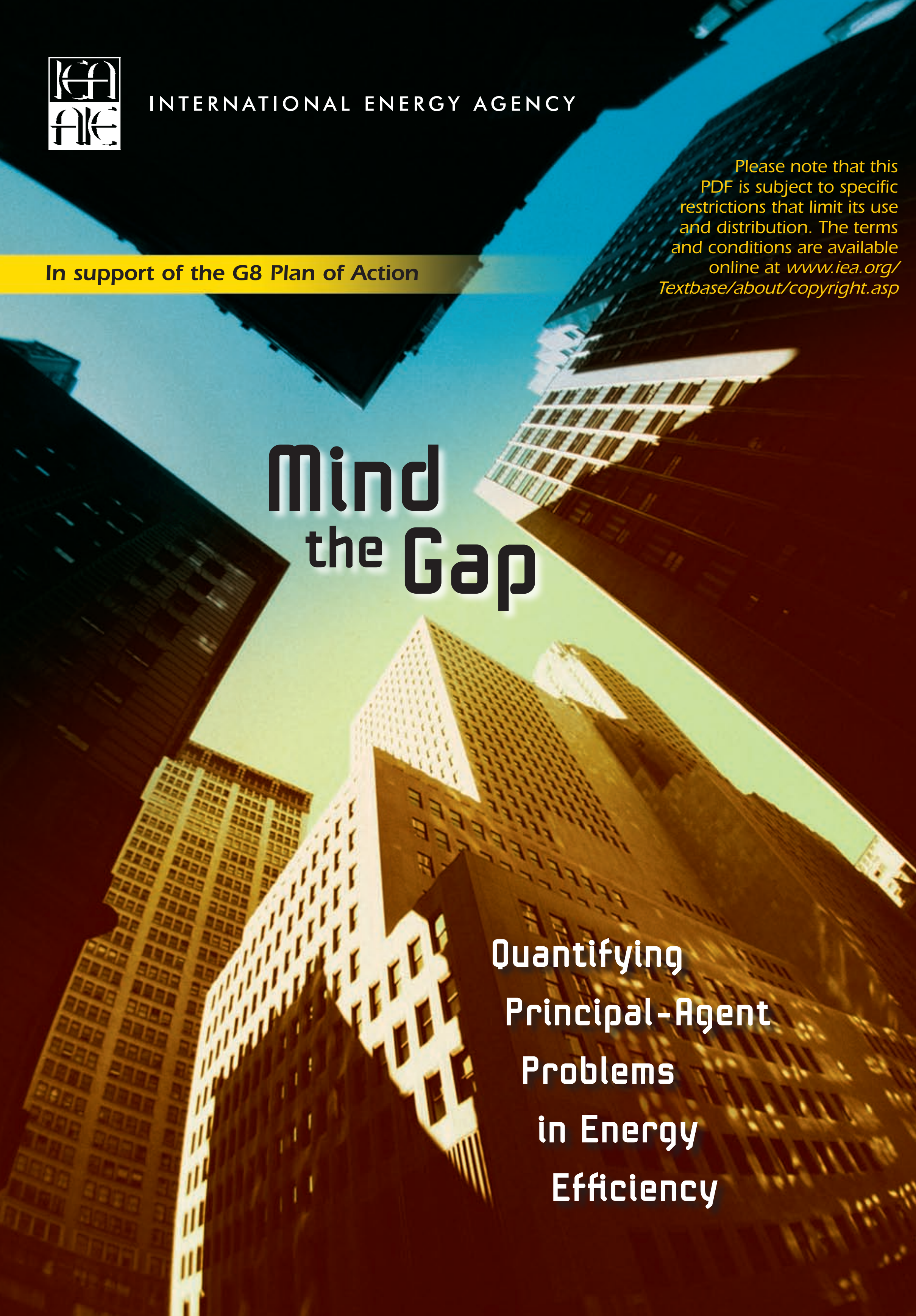

INTERNATIONAL ENERGY AGENCY

In support of the G8 Plan of Action

Mind the Gap

Quantifying Principal-Agent Problems in Energy Efficiency

INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA) is an autonomous body which was established in November 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme.

It carries out a comprehensive programme of energy co-operation among twenty-six of the OECD thirty member countries. The basic aims of the IEA are:

- To maintain and improve systems for coping with oil supply disruptions.
- To promote rational energy policies in a global context through co-operative relations with non-member countries, industry and international organisations.
- To operate a permanent information system on the international oil market.
- To improve the world's energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use.
- To promote international collaboration on energy technology.
- To assist in the integration of environmental and energy policies.

The IEA member countries are: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Republic of Korea, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States. The Slovak Republic and Poland are likely to become member countries in 2007/2008. The European Commission also participates in the work of the IEA.

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of thirty democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Republic of Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States.
The European Commission takes part in the work of the OECD.

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FOREWORD

The imperative to improve energy efficiency is now stronger than ever. Energy efficiency must be one of the strategies employed to address the challenges of energy security, climate change and economic development.

It is encouraging to see the importance of energy efficiency reaffirmed by political leaders. Recent meetings of the G8 Heads of State, for example, (2005 Gleneagles, 2006 St Petersburg and 2007 Heiligendamm) and the IEA Governing Board (May 2007) identified the critical role of improved energy efficiency.

The IEA analysis consistently identifies significant cost-effective energy efficiency potential. We know the potential is there. But, despite these low-hanging fruit, much of this energy efficiency potential is not realised. Market barriers continue to prevent optimal energy efficiency.

This book provides a detailed analysis of one of these market barriers: principal agent problems – or, in common parlance, variations on the 'landlord-tenant' problem.

This book is an innovative approach to energy efficiency analysis. It is the first time any study has attempted to estimate the size of the principal-agent problems. We use 8 case studies from 5 OECD countries across 3 sectors. In many of these contexts we identify that PA problems affect a significant proportion of end-use energy. The 8 case studies reveal that over 3 800 PJ/year of energy use is affected by such barriers – that is around 85% of the annual energy use of Spain. The book also provides a set of possible solutions to PA problems. Such solutions can significantly reduce PA problems and enhance energy efficiency.

This work is published under my authority as Executive Director of the International Energy Agency and does not necessarily reflect the views of the IEA member countries.

Nobuo Tanaka
Executive Director

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Carol May edited the book.

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EXECUTIVE SUMMARY

Energy efficiency presents a unique opportunity to address three energy-related challenges: energy security, climate change, and economic development. Past experience shows that energy efficiency has delivered significant benefits. Since 1973, if energy efficiency policies had not been put in place, worldwide energy consumption would be 50% higher. It is estimated that by 2030 up to 83 EJ more energy could be saved if a range of cost-effective energy efficiency measures were implemented (International Energy Agency, 2007a).

Yet, there is an energy efficiency gap. A significant proportion of the energy efficiency improvement potential is not realised – a result of barriers in the energy market. These market barriers inhibit energy efficiency improvements. They take many forms, ranging from inadequate access to capital, isolation from price signals, information asymmetry, and split-incentives. Though many studies have reported the existence of such market barriers, none so far have attempted to quantify the magnitude of their effect in the energy efficiency market.

This book provides a unique insight into barriers to energy efficiency. It provides a methodology and a first attempt at quantifying the size of one type of barrier to energy efficiency: Principle-Agent (PA) problems. PA problems refer to the potential difficulties that arise when two parties engaged in a contract have different goals and different levels of information. Although in some cases energy savings potentials are also analysed, the main purpose of this book is to highlight the amount of energy that is being affected by this particular market barrier.

The study draws on eight case studies from five IEA countries — Japan, the United States, the Netherlands, Norway, and Australia — in the residential, commercial and end-use sectors. In doing so, this book estimates the magnitude of energy that is affected by PA problems in each context. Analysis of the case studies provides policymakers with valuable insights into the significance of the problem and, where necessary, guidance on implementing additional policy measures to overcome these market barriers to energy efficiency.

To identify the existence of PA problems, the study looks at the affected energy use in each country and sector under consideration following a given methodology. This allows the identification of the amount of energy insulated from the price of energy. Each case study proceeds to: *i)* identify situations where PA problems potentially exist and evaluate the roles of the parties and their transactions; *ii)* estimate the number of end-users affected by PA problems; and *iii)* estimate the affected energy use for each of the affected populations.

Overall, the study finds significant evidence of PA problems—ranging from around 30% of sectoral energy use to negligible effect in the various sectors studied. In absolute terms, the book estimates that over 3 800 PJ/year of energy use is affected by PA problems in the case studies examined – equivalent to around 85% the total energy use of Spain in 2005.

Four main policy lessons can be drawn from the case studies to help policy makers reduce the energy efficiency gap. First, small things add up. While PA problems affect little amounts of energy use at the individual level, whether landlord-tenants or in vending machines, when aggregated, the problem is significant.

Second, PA problems are pervasive, disbursed and complex. As such, no single policy instrument is sufficient to overcome PA problems. Neither regulatory mechanisms, (*e.g.* minimum energy performance standards, or regulated contract design), nor information-based instruments (*i.e.* awareness campaigns) alone will resolve them. Instead, governments should help design well-targeted policy packages to address PA problems in their specific national contexts, and within the particular constraints of a given sector. These packages should include measures to: a) address contract design to ensure end-users face energy prices, b) regulate the level of energy efficiency in appliances and buildings, c) improve access to information about energy efficiency performance.

Third, the national context plays a key role in the potential success or failure of energy efficiency policy. Important contextual factors include institutional support for energy efficiency, the price of energy and public awareness of the importance of energy efficiency. The latter two points in particular have emerged as important influences on PA problems.

Finally, evidence presented in this study is only the tip of the iceberg. With only a few case studies, this book has highlighted significant energy savings potential. Further savings are all the more likely given that this study makes a range of conservative assumptions. More systematic analysis of both PA problems and other barriers is likely to identify further significant potential savings and assist policy makers to 'mind the energy efficiency gap'.

INTRODUCTION

The world is facing a set of complex energy challenges: security of energy supply, access to affordable energy for all, and countering climate change.

Soaring energy prices and recent geopolitical events have reminded us of the essential role affordable energy plays in economic growth and human development. The global energy system is vulnerable to supply disruptions. Increasing energy-related tensions – as illustrated by the Russia/Ukrainian gas crisis in early 2006 – have raised energy security concerns and energy efficiency. Safeguarding energy supplies is thus again at the top of the international policy agenda.

Moreover, global CO_2 emissions have increased by more than 20% over the last decade. Oil demand and CO_2 emissions will continue to grow rapidly over the next 25 years, and these trends are likely to get worse (International Energy Agency, 2006).

Energy efficiency plays an indispensable role in addressing these challenges. Energy efficiency leads to more energy services – such as production, transport, and heat – per unit of energy used (*i.e.* coal, gas, electricity). Higher levels of energy efficiency produce many benefits, including increased energy security, reduced energy costs, and lower environmental impacts.

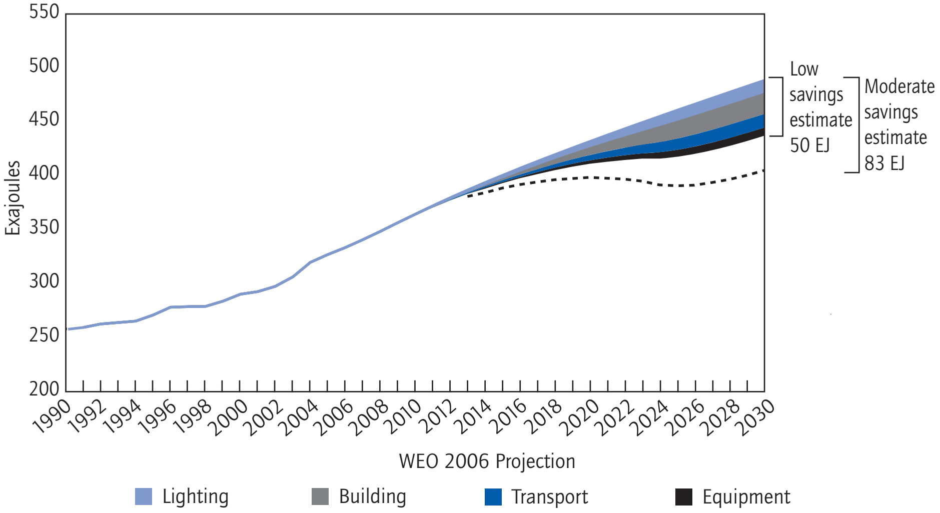
By reducing reliance on imported energy sources, energy efficiency makes an important contribution to increased energy security. Energy efficiency also reduces energy costs. While the initial cost of some energy-efficient technologies can be higher than their less-efficient counterparts, the majority of these technologies are cost-competitive when analysed on a life-cycle cost basis (IEA, 2007). Energy efficiency is also widely seen as the most important near-term strategy to mitigate CO_2 emissions (IEA, 2006). As a result of these drivers, energy efficiency is a top priority for policy makers.

Many energy efficiency improvements can be made using existing technologies and practices across all end-use sectors. Cost-effective solutions already exist, and include more efficient appliances, improved energy management for commercial buildings, improved residential heating and cooling, industrial process efficiency, and vehicle efficiency measures, among others. In cold climates where most of the energy consumed is spent on heating, energy use can be reduced significantly by improved checking processes on insulation, fewer infiltrations and leakages, and more efficient heating systems (especially boilers). In a hot climate, on the other hand, properly designed ventilation systems, adequate solar protection, or building inertia and insulation can reduce the need to use air conditioning.

Figure 1 demonstrates the significant energy saving potential from a range of currently cost-effective energy efficiency policies. Despite the availability of such potential savings, energy efficiency remains underutilised. A key reason is the existence of market barriers, which take many forms ranging from a lack of information and split incentives (also known as Principal-Agent problems) to access to capital.

FIGURE 1

Impact of Concrete 2006 & 2007 IEA Recommendations on World Final Energy Consumption



Source: International Energy Agency 2007a.

A number of studies have discussed and established the existence of these barriers (Guertler, 2005; The Productivity Commission, 2005; DeCanio & Watkins, 1998). However, two issues have had little attention in the barriers literature. First, relatively few studies have focused in detail on PA problems (see Chapters 1 and 2) as it relates to energy efficiency. Second, there has been little attention given to quantifying the magnitude of the effect of barriers on energy use.

The book seeks to address this gap in this energy efficiency barrier literature. The purpose of the book is two fold: establish a methodology and quantify the amount of energy affected by the PA problems. Although some energy savings potentials will be presented where possible, the main purpose of the book remains to underline the amount of energy that is being affected by the PA problems.

PA problems in general refer to the potential difficulties that arise when two parties engaged in a contract have different goals and different levels of information. In the context of energy efficiency, PA problems can lead to sub-optimal levels of energy efficiency (see Chapter 2 for more detailed exploration of the theory behind PA problems). Focusing on the PA problems, the book estimates the amount of energy which is isolated from consumers' decisions.

The book includes eight case studies from five different OECD countries, including Japan, the United States, the Netherlands, Norway, and Australia, that analyse and quantify potential PA problems in the residential, commercial, and end-use sectors.

The first section of this book (Chapters 1-3) provides background on the economic theory and methodology on which the book is based. It includes definitions, a literature review on market barriers to energy efficiency, and the economic theory that forms the basis for analysing PA problems. Readers familiar with this material may wish to move straight to the second section of the book. Chapter 3 provides an explanation of the methodology used in the case studies.

The second section of this book presents case studies that address set-top boxes and refrigerator, water heater, space heating and residential lighting in the United States, space heating in the Netherlands, vending machines in Australia and Japan, as well as commercial offices in Norway, the Netherlands and Japan. Each case study outlines the national context, the energy use in the sector being analysed, the size of the potential PA problems, the energy policy context, and policy lessons.

The third section completes the book with a summary, analysis, policy recommendations, and conclusions based on the results of the case studies. It is hoped that this assessment will guide policy makers in developing and targeting policy solutions to accelerate progress in energy efficiency.

Theory

① Market barriers to energy efficiency improvements: locating Principal-Agent problems within the broader context

② Agency Theory and Principal-Agent problems

③ Methodology

MARKET BARRIERS TO ENERGY EFFICIENCY IMPROVEMENTS: LOCATING PRINCIPAL-AGENT PROBLEMS WITHIN THE BROADER CONTEXT

Introduction

The purpose of this chapter is to discuss how energy efficiency-related PA problems relate to the broader context of market barriers and market failures. The chapter begins by establishing the existence of an "energy efficiency gap" – energy efficiency's untapped potential. Then the chapter discusses possible reasons for this energy efficiency gap, including the existence of market barriers and market failures that include PA problems. According to economic theory, as a market failure, PA problems deserve special attention from governments.

The energy efficiency gap

Many studies have attempted to quantify the potential for energy efficiency improvement (Intergovernmental Panel on Climate Change, 2001; Productivity Commission, 2005; International Energy Agency, 2006). The Intergovernmental Panel on Climate Change (IPCC) found that cost-effective energy efficiency improvements could contribute to half the potential emission reductions by 2020[1](Intergovernmental Panel on Climate Change, 2001). More recently, the IEA's World Energy Outlook (International Energy Agency, 2006) and the IPCC 2007 Working Group III identify energy efficiency's significant potential to reduce greenhouse gas emissions over the next 20 to 30 years.

A range of technologies and options contribute to this potential. For example, if all conventional incandescent lamps world wide were replaced by compact

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[1] Net capita, operating and maintenance costs.

fluorescent lamps (CFLs) roughly 2 880PJ and 470 $MtCO_2$ emissions in 2010 could be saved, rising to 4 320 PJ and 700 $MtCO_2$ in 2030. Cumulatively this would reduce global net lighting costs by USD 1.3 trillion from 2008 to 2030, and avoid 6.4 Gt CO_2 emissions at negative abatement cost of USD -205 per tonne (International Energy Agency, 2007a). The potential cost-effective savings from improvements in heating, cooling, ventilation and hot water in the building sector, which accounts for approximately 40% of all energy use, are at least 20 EJ per year by 2030.

Yet evidence suggests that a significant proportion of energy efficiency improvement potential is not realised. The difference between the actual level of energy efficiency and the higher level that would be cost-effective from the individual's or firm's point of view is often referred to as the 'efficiency gap'. Many studies have documented the existence of this gap. (Interlaboratory Working Group, 2000; Ecofys, 2001; Intergovernmental Panel on Climate Change, 2001; Greenpeace International and European Renewable Energy Council, 2007).[2]

The existence of the energy efficiency gap is often explained by the presence of 'market failures' and 'market barriers' to energy efficiency (International Energy Agency, 2003).

Market barriers, market failures and energy efficiency

All markets for goods and services can be said to experience 'barriers' to some extent or another. For example, the producer of an electronic device may claim, rightly or wrongly, that the lack of public knowledge about the device is a 'barrier' to its increased market penetration. In some cases, the producer may go so far as to argue that government should intervene to help remove barriers to its products.

Markets for energy efficiency also experience 'barriers'. In the context of energy efficiency, the term market barrier refers to any market-related factor that inhibits energy efficiency improvements (Intergovernmental Panel on Climate Change,

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[2] Although there is some debate about the actual existence of the energy efficiency gap (see for example Sutherland, 1991).

2001). The energy-efficiency literature documents several market barriers to increased levels of energy efficiency (see for example DeCanio, 1993; Ingham, 1991; Sorrell, 2004; and Sathaye, 2004). These and other studies have analysed and confirmed the existence of a range of market barriers, including the low priority many consumers and businesses place on reducing energy costs through energy efficiency improvements and access to capital.

Energy policy analysts commonly identify a subset of market barriers called market failures (see for example Productivity Commission, 2005; Brown, 2001; and the IEA, 2005). These market failures include PA problems (see Chapter 2), insufficient information, and externalities (costs that are not reflected in energy prices, such as the environmental and health damages associated with energy production and use).

It is important to identify market failures because, according to neoclassical economics, only those barriers that are market failures lead to inefficient allocation of resources. Thus, according to the theory, government intervention is justified because it can deliver the much sought after Pareto efficiency.[3]

This is not to say that government intervention is only justified in the presence of market failures. For pragmatic reasons, governments may wish to intervene to address non-failure barriers in order to achieve a range of policy goals such as meeting a policy target, or to increase the rate of energy efficiency uptake to achieve environmental goals.

Market barriers to energy efficiency are very diverse and are classified in a variety of ways (see for example, IPCC, 2001; Sorrel, 2004; and Brown, 2001; and IEA, 2003). The following figure provides one possible classification for market barriers and market failures (see Figure 2).

This list is not comprehensive and is not meant to suggest that the individual barriers are tight categories. The barriers overlap and there is interaction between them and their effects on decisions to invest in energy efficiency.

The next two sections discuss market barriers and market failures in more detail. The discussion provides a foundation for the discussion of PA problems in Chapter 2.

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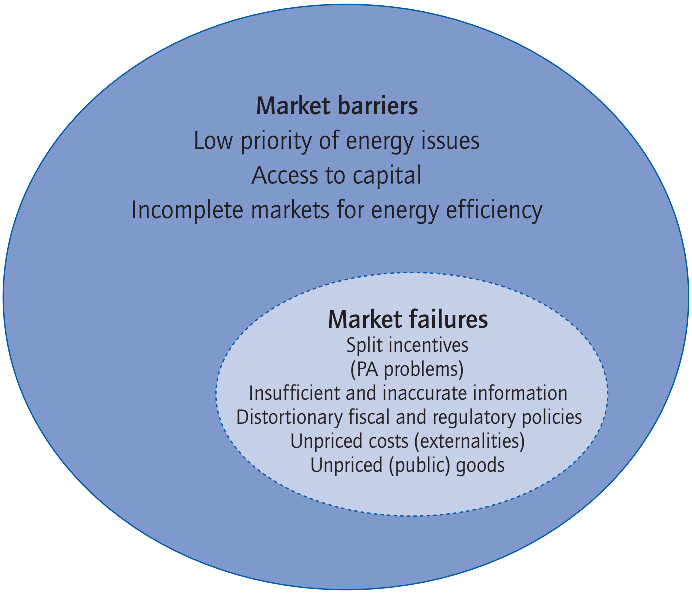
[3] When resources are arranged such that no rearrangement of those resources can make someone better off without making another worse off.

FIGURE 2

Market barriers and market failures inhibiting energy efficiency improvements



Market barriers

Market barriers to energy efficiency occur as a result of three conditions: when energy costs are a low priority relative to other factors, when barriers in capital markets inhibit the purchase of energy-efficient technologies, and when energy-efficient markets are incomplete.

Low priority of energy issues

In many instances, energy efficiency is not a major concern for consumers or firms because energy costs are low relative to the cost of many other factors (such as labour costs). Consequently, there is little incentive to invest in energy efficiency improvements. Examples of this are well-documented. In the office space market in London, energy costs are equivalent to 1%-2% of rental costs (Guertler *et al.*, 2005). In Australia, energy costs represent about 2.5% of total expenditures in the residential sector, 1.6% of total expenditures in the commercial sector, and less than 3% of total expenditures in many (but not all) industrial sectors (Productivity Commission, 2005).

Since energy costs are typically small relative to other costs, it is easy for consumers to ignore them. This may also mean that the benefits from energy savings to individuals may be outweighed by the transaction costs (*e.g.* costs of gathering information and perceived inconvenience of installing new equipment). Numerous studies demonstrate that consumers invest in upgrades of their buildings, appliances, cars, and other equipment for safety, health, comfort, aesthetics, reliability, convenience, and status reasons. Energy efficiency rarely is a high priority issue relative to these other factors.

It is important to note that, even though at an individual level energy costs may be insignificant, when summed over all individuals, energy can represent a significant cost to society. Governments may wish to promote energy efficiency as a cost-effective method for reducing energy use and achieving other policy goals such as improved energy security and environmental sustainability.

Access to capital

Access to capital can be a barrier to investment in any technology, and energy efficiency is no exception. For example, residential and small commercial energy users face much higher finance costs than large businesses and utilities. As a result, it can be difficult for some energy users to access the capital necessary to make energy efficiency improvements.

In addition, many energy efficiency projects do not qualify for traditional sources of financing or may not qualify under conventional lending criteria. A study undertaken by DeCanio (1993) showed that firms typically establish internal hurdle rates for energy efficiency investments that are higher than the cost of capital to the firm. Furthermore, energy efficiency investments are often small scale and dispersed and it can be difficult to quantify all of the benefits from the investments. As a result, financial institutions that are unfamiliar with energy efficiency can be reluctant to lend for energy efficiency improvements.

Incomplete markets for energy efficiency

Energy efficiency is often a secondary attribute bundled together with other product features. For example, the fuel economy of automobiles has historically been only one of a large number of features that come in a package for each make and model. Or in the case of electrical appliances, the standby power use is a part of the overall appliance package intended to provide a service like watching television or listening to music. In these situations, there is not really a separate, or complete, market for energy efficiency unless a separate energy efficiency option is available.

Energy efficiency may be bundled together with other product attributes because of historically-low energy prices and a general lack of interest in energy efficiency features. With increasing energy prices, one might expect products to emerge with separate energy efficiency options. If this does not happen then governments may decide to intervene.

Market failures

"Market Failures" occur when one or more of the conditions necessary for markets to operate efficiently are not met. According to neoclassical economic theory, markets operate efficiently (that is "perfect competition") when:

- there are sufficiently large numbers of firms so that each firm believes it has no effect on price;
- all firms have perfect information;
- there are no barriers to enter or exit the market place;
- firms are rational profit maximisers;
- transactions are costless and instantaneous.

When any of these ideal conditions are not met, there is a market failure, and markets are not achieving a Pareto optimal allocation of resources. In the context of energy efficiency, a market failure would imply that more energy is being consumed for the level of service than a rational allocation of resources would justify, in light of consumers and producers preferences.

Market failures provide a minimum justification for government policy intervention to improve efficiency. However, because market failures are pervasive, the mere existence of market failure is not sufficient to justify government intervention. It is also necessary to demonstrate that the benefits arising from an intervention exceed the cost of implementation.

There is ample evidence of market failures with respect to energy efficiency in the literature (DeCanio, 1998; Howarth *et al.,* 2000). Two market failures, split incentives and asymmetric information (discussed in more detail in Chapter 2) relate directly to the PA problems addressed by this book.

Split incentives

Split incentives occur when participants in an economic exchange have different goals or incentives. This can lead to less investments in energy efficiency than could be achieved if the participants had the same goals. A classical example in energy efficiency literature is the 'landlord-tenant problem', where the landlord provides the tenant with appliances, but the tenant is responsible for paying the energy bills. In this case, landlords and tenants face different goals: the landlord typically wants to minimise the capital cost of the appliance (with little regard to energy efficiency), and the tenant wants to maximise the energy efficiency of the appliance to save on energy costs.

Split incentives occur in the property ownership market, where many homeowners and businesses have limited incentive to invest in efficiency measures because they do not expect to stay in their building long enough to realise the payback from investments in energy efficiency. Split incentives also occur in the hotel industry, where the occupant seeks to maximise comfort and does not directly pay for the room's energy use. The hotel owner, on the other hand, does face the energy costs – which is why many hotels typically install compact fluorescent lamps and keys that deactivate a room's energy use when removed from their slots.

Insufficient and inaccurate information

Imperfect (insufficient and/or incorrect) information can cause firms to make suboptimal investments in energy efficiency.

Evidence that imperfect information affects investments in energy efficiency is widespread. DeCanio (1998) found that firms often lack the ability or time to process and evaluate the information they have, a situation sometimes referred to as "bounded rationality".

A common example of imperfect information is the belief that energy-efficient products are more expensive than their less efficient counterparts. A recent IEA analysis suggests that this is not always true (International Energy Agency, 2007b). The IEA found that in countries where energy efficiency regulations have been implemented, there have not been sustained increases in the real prices of regulated household appliances.

Sanstad and Howarth (1994) point out that there is a large body of research documenting that consumers are often poorly informed about technology characteristics and energy efficiency opportunities. Another study of 12 Dutch industrial firms found that the cost of collecting information on energy efficiency investments can be substantial – 2% to 6% of the total cost of the efficiency investment (Hein and Blok, 1995). Similar transaction costs can be expected for the commercial sector, but are likely to be higher (although more difficult to quantify) than for residential consumers. Some non-governmental organisations have attempted to fill part of the energy efficiency information gap, including the Consumer Report magazine in the USA and Consumer in New Zealand.

Issues with respect to information are intimately related to the PA problems discussed in the next chapter, which presents the theory behind PA problems. This provides the framework for the remainder of the book, which identifies and quantifies actual PA problems in a range of energy efficiency case studies.

AGENCY THEORY AND PRINCIPAL-AGENT PROBLEMS

This chapter describes the content, strengths and weaknesses of Agency Theory, the theory behind Principal-Agent problems. The chapter also describes how PA problems apply to energy efficiency and provides the foundation for the methodology (Chapter 3) used in the eight case studies.

Readers familiar with this theory, or those interested in the practical aspects of this study, may prefer to go directly to the next chapter.

Agency Theory

General description of Agency Theory and Principal-Agent problems

Agency Theory is now very much a part of mainstream economics. Agency Theory and PA problems in economics refer to the potential difficulties that arise when two parties engaged in a contract have different goals and different levels of information (Lipsey, 1983; Eisenhardt, 1989; Wright *et al.*, 2001; Lange, 2005). The general arrangement is for a principal to pay an agent for some good or service. The principal is therefore the party who pays the agent for either:

a) the agent to act on the principal's behalf, or

b) the agent to provide some service to the principal.

For example, an owner/employer (principal) pays an employee (agent/manager) to act on its behalf. The employee is then responsible for providing the service (*e.g.* producing goods to sell) and purchasing any equipment.

Agency Theory argues that two important conditions pervade relationships between principals and agents. First, the Theory assumes that "agents are autonomous and are prone to maximising their own interests at the expense of principals" (Sharma, 1997, p. 759). In other words, there is a general assumption of goal conflict between the principal and the agent.

The energy efficiency literature tends to refer to this problem of goal conflict as split incentives.

A second condition permeating relationships between principals and agents is a problem of information asymmetry[4] between the two parties. In economics, information asymmetry exists when one party to a transaction holds relevant information, but is unable or unwilling to transfer this information to the other party. Typically the seller knows more about the product than the buyer.

As a consequence of these two pervasive conditions, two PA problems arise: adverse selection and moral hazard.

Adverse selection

The problem of adverse selection occurs when one party acts opportunistically[5] *prior* to entering into a contract. Akerloff's (1970) model of the second-hand cars market provides the classic demonstration of the adverse selection problem. Because it is very difficult for a potential buyer to identify a car with significant mechanical problems (a "lemon") before buying it, buyers are at the mercy of opportunistic sellers. Opportunistic behavior of the seller can lead to the purchaser unwittingly selecting a lemon.

Moral hazard

The moral hazard problem, on the other hand, occurs when a party acts opportunistically *after* a contract is signed. For example, after an insurance contract is signed, there is always a temptation to cheat and claim more from the insurance company than is justified in the contract.

Strengths and weaknesses of Agency Theory

Proponents of Agency Theory identify the Theory's three important strengths: its broad applicability, its explanatory power, its solution focus. First, Agency Theory is applicable to a broad field of enquiry. The literature on Agency Theory began by examining agency relationships between managers of companies (the agent) and shareholders (the principal). Agency Theory has

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[4] A special case of imperfect information (see Chapter 1 discussion of market failures).

[5] Where "opportunism" is defined as "self-interest seeking with guile" (Williamson, 1985, p. 47).

extended to agency relationships in a wide range of contexts. This broad application of the Theory leads Sorrell *et al.* (2004, p. 41) to state that PA relationships "pervade both markets and organisations". Proponents urge the adoption of an Agency Theory perspective when investigating the many problems that exist in relationships that have a principal-agent structure (including in an energy efficiency context).

A second strength identified by Agency Theory proponents is the Theory's explanatory power. For example, Wright *et al.* (2001, p. 414) state that "by narrowly focusing on the principal-agent relationship, and with a given set of assumptions, the contribution of this Theory is that it provides logical predictions about what rational individuals may do if placed in such a relationship". As a result, Agency Theory "provides a unique realistic, and empirically testable perspective on problems of cooperative effort" (Eisenhardt, 1989, p. 72). This strength of the Theory is used to estimate the level of energy use affected in PA problem situations (see Chapters 4-14).

Finally, Agency Theory is focused on solutions to PA problems. The major contribution of Agency Theory is that economic inefficiency is inevitable in principal-agent relationships. The Theory turns naturally to considering the ways in which the relationship between agents and principals can be made more efficient. That is, Agency Theory focuses on improving the contracts between parties.

Agency Theory is clear that no single form of contract will solve all agency problems. However, when designing contracts, theory suggests that the best contract is one that aligns the interests of principal and agent as much as possible. Agency Theory attempts to identify the various contract alternatives, and which contract is the most efficient under varying levels of outcome uncertainty, risk aversion, and information.

Despite the obvious insights that Agency Theory provides into issues such as PA problems, the Theory has many critics (see for example, Mitncik, 1992; Lubatkin, 2005; and Sorrell, 2004). Critiques of Agency Theory centre around two issues: its ability to adequately portray real-world situations, and the completeness of the Theory.

Several authors argue that Agency Theory is not able "to explain the complexities of real-world organisations" (Lubatkin, 2005, p. 213). Critics maintain that much of Agency Theory literature "employs complex and highly formalised mathematical models whose utility in explaining real-world organisational arrangements must be questioned" (Sorrell *et al.*, 2004, p. 43). These limitations arise because the theory is reductionist and makes three inappropriate assumptions (Lubatkin, 2005):

- that opportunism is pervasive, whereas, people are motivated by more than just money; they also have needs for achievement, responsibility, recognition... [and] people are capable of a full range of actions, varying from self-serving with guile to owner-serving to altruistic;
- that actors in the principal-agent relationship are portrayed as simply "dispassionate 'Homoeconomicus'" individuals, whereas people are more complex;
- information asymmetry is pervasive, whereas this may not always be the case.

It is argued that the Theory is too narrow because its assumptions discount contingencies that may be more reflective of realities in economic relationships.

A second criticism of Agency Theory is that the Theory is as yet incomplete. Sharma (1997) notes that the persistence of agency problems in many sectors of the economy raises questions about the completeness or even appropriateness of the mainstream agency perspective. However, the incompleteness of the Theory may not be a problem *per se*. "Unresolved issues in the Theory provide the impetus to explore factors that impede application of agency solutions and, for that matter, to scrutinise Theory itself so that its structure may be refined further" (Sharma, 1997, p. 762).

These criticisms are well made. However, no theory will be a panacea. And, despite these criticisms, the Theory can provide sufficient insight into issues relevant to this book. Agency Theory arguably does serve as an attempt to look inside the black box of relationships between economic actors.

Summary of Agency Theory

The core aspects of Agency Theory can be summarised in Table 1. This table uses the example of the owner-manager relationship to illustrate the Theory because it is a commonly studied situation in economic literature.

TABLE 1

Critical aspects of an Agency Theory enquiry

Dimension	Owner-Manager
Unit of analysis	Relationship (and contract) between owner (principal) and manager (agent)
Problem domain	Relationships in which the principal and agent have different levels of information, and partly differing goals
Goal orientation of the actors	Goal conflict between principal and agent. Owner's goal is to maximise returns. Manager's goal may be to limit work levels required.
Key objective	Principal-agent relationships should reflect efficient organisation of information to maximise economic efficiency
Human assumptions	Self-interest Bounded rationality Individual autonomy
Organisational assumptions	Partial goal conflict Economic efficiency as the criterion Information asymmetry Agent delegated the task by passive owner principal
Assumption about the source of problem	Contract inadequate
Implications of inefficient relationship/contract	Adverse selection Moral hazard Split incentives

Source: based on Sharma, 1987.

Agency Theory, Principal-Agent problems and energy efficiency

Several authors have attempted to apply insights from Agency Theory to energy efficiency. From these studies, there appears to be consensus that some problems with investments in energy efficiency “may be understood through the logic of the Principal-Agent problem” (Howarth *et al.*, 2000, p. 482).

Indeed, in the context of energy efficiency, the relevance of Agency Theory is clear. Energy efficiency transactions invariably involve the core elements of an Agency Theory perspective:

- a principal (for example, tenant or shareholder) and an agent (for example, landlord or manager);

- the problem of goal divergence between a principal and agent (for example, a landlord wanting to minimise capital cost and a tenant wanting to minimise energy cost);
- the problem of asymmetric information (where, for example, the appliance salesperson knows the energy efficiency of the refrigerator and does not share this with the purchaser);
- The consequent adverse selection and moral hazard problems.

The application of Agency Theory to energy efficiency requires further explanation with respect to:

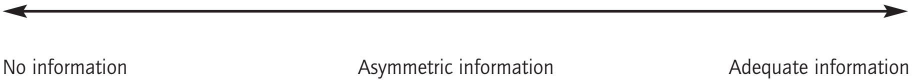
- problem definition;
- information and market failures;
- the types of relationships between principals and agents.

Problem definition

PA problems in neoclassical economics focus on the relationship between a principal and agent and how to use contracts to reduce agent opportunism at the expense of the principal with the goal of improving economic efficiency. In the energy efficiency context, the PA problem definition is extended to focus on the (contractual) relationship between a principal and agent and to understand how that influences the energy efficiency of the system (Sorrell *et al*., 2004, p. 28).

Information and market failures

As discussed in Chapter 1, according to economic theory, the existence of imperfect information is a market failure and warrants possible policy intervention. In the context of energy efficiency, the issue of access to information relates to both information about the energy performance of technology, as well as information about the marginal cost of energy use. The quality and extent of information relating to equipment's energy performance may be thought to lie along a spectrum:



At one end of the spectrum there is no information. Even the equipment manufacturers may not know the expected annual energy consumption of their devices.

Further along the spectrum, manufacturers may know the efficiency of their products, but are not required to provide the information to purchasers. In this case, neither the purchaser (for example, landlord) nor the user (for example, tenant) has enough information to know how the equipment will perform with respect to its energy efficiency. In this case, one cannot say that there is a PA problem because the agent cannot know whether they are acting in the principal's interests or not.

In the middle of the spectrum, information is available, but its distribution is asymmetric. The landlord has the opportunity to inspect energy efficiency labels before purchase, but then he or she can remove the labels before installing them in their rental units. An unscrupulous landlord could claim that the appliances are particularly energy efficient even when they are not.

At the other end of the spectrum, both the principal and the agent have adequate information to know whether the equipment is the best choice. However, even with perfect information, the principal's inability to control the agent's actions may still produce a PA problem. For example, without adequate enforcement ability, even a fully informed tenant cannot force a landlord to buy a more efficient end-use device.

The other information problem that could warrant policy attention is when the purchaser of energy efficiency equipment or the energy user are "insulated" from the marginal cost, or price, of energy use. This is a common situation in several energy-related contexts, and depends on the relationships between principals and agents.

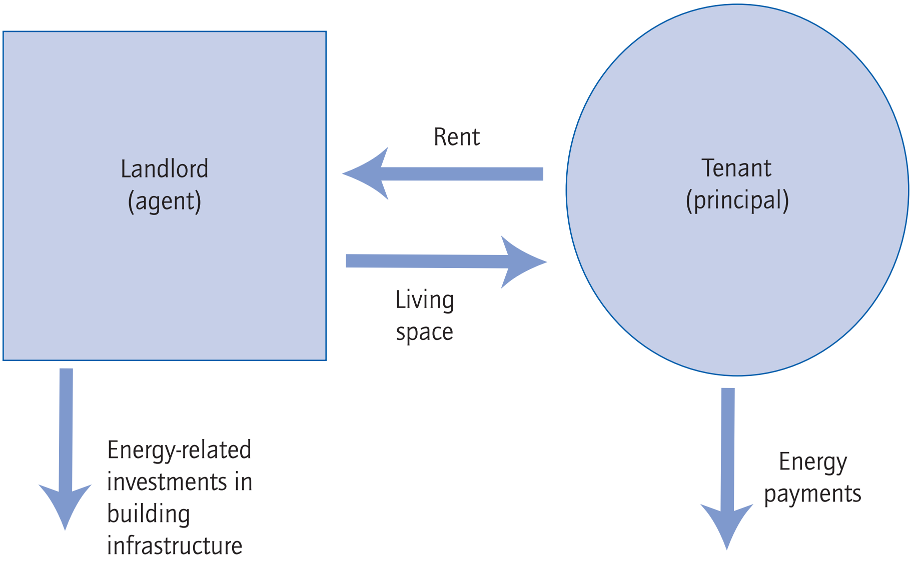
Relationships between principals and agents

The common principal-agent relationship described in energy efficiency studies is the landlord-tenant situation, shown in Figure 3.

In this example the tenant pays rent to the landlord in exchange for use of the building. The tenant pays energy costs that are largely determined by the infrastructure present in the building. The landlord makes (or declines to make) investments in the building so as to lower its energy consumption. The landlord has no incentive to make efficiency investments because only the tenant benefits

FIGURE 3

Energy-related transaction between a landlord and a ten-



from these reduced costs. If energy prices rise, the landlord still lacks any incentive to respond by making additional investments in efficiency. In this way, it can be said that the energy consumption is somewhat "insulated" from energy prices.

The relationship described in Figure 3 is a common situation. But other relationships can exist between the principal and agent regarding responsibility for investments in efficiency and payment of energy costs. Table 2 depicts the four possible relationships using the landlord-tenant situation to illustrate the issues.

TABLE 2

Transactions from an end-user perspective

	End user can choose the technology	End user cannot choose the technology
End user pays the energy bill	Case 1: No PA problem (principal and agent same entity)	Case 2: Efficiency problem (agent selects end using technology, principal pays the energy use)
End user does not pay the energy bill	Case 3: Usage and efficiency problem	Case 4: Usage problem

Summary

It is possible to summarise the specific characteristics of energy efficiency alongside the standard application of Agency Theory shown in Table 1. Since the domain of Agency Theory is very broad, for comparison the owner-manager agency relationship is used to represent the standard application of Agency Theory, and the landlord-tenant example to represent the energy efficiency context.

TABLE 3

Summary of aspects of Agency Theory applied to energy efficiency

Dimension	Standard application of Agency Theory (Owner-Manager)	Energy efficiency context (Landlord-Tenant example, Case 2)
Unit of analysis	Relationship (and contract) between owner (principal) and manager (agent)	Relationship between tenant (principal) and landlord (agent)
Problem domain	Relationships in which the principal and agent have different levels of information and partly differing goals	Relationships in which the principal and agent have different levels of information, and partly differing goals
Goal orientation of the actors	Goal conflict between principal and agent. Owner's goal is to maximise returns. Manager's goal may be to limit work levels required	Goal conflict. Landlord's goal is to minimise capital cost (*e.g.* of energy using technology) and maximise rent return. Tenant's goal is to minimise their own costs including energy
Key objective	Principal-agent relationships should reflect efficient organisation of information to maximise economic efficiency	Principal-agent relationships should maximise both economic and energy efficiency of the system
Human assumptions	Self-interest Bounded rationality Individual autonomy	Self-interest Bounded rationality Individual autonomy
Organisational assumptions	Partial goal conflict Economic efficiency as the criterion Information asymmetry Agent delegated tasks by owner (principal)	Partial goal conflict Economic and energy efficiency as the criteria Information asymmetry Agent delegates use of capital to principal
Assumption about the source of problem	Contract inadequate	Contract inadequate Goal differences, imperfect, and/or asymmetric information (about technology or energy price/energy cost)
Implications of inefficient relationship/ contract	Adverse selection moral hazard	Adverse selection moral hazard inefficient energy use

An important point to note from this discussion is that the solutions to PA problems in the energy efficiency context are varied, depending on the source of the problem. If the problem relates simply to goal differences, then the solution may lie in amending the contract. A contractual solution may also help alleviate some situations of information asymmetry (*e.g.*, where the user is "insulated" from the energy price). However, contractual solutions have their limits. Therefore, there may be some situations where PA problems cannot be addressed through contracts alone. In these situations, policy intervention may be justified.

Past applications of Agency Theory to energy efficiency issues

There have been relatively few applications of Agency Theory to energy efficiency issues. This lack of attention is surprising because the theoretical apparatus to examine the subject of energy efficiency is at least available in the Agency Theory.

Agency Theory can provide useful insights into many of the energy efficiency situations that occur in firms. Investigations by DeCanio (1993, 1994) in the United States, followed by Sorrell in the UK (Sorrell *et al.,* 2004) , Saele (2005) in Norway, and Schleich and Gruber (2006) in Germany all provide evidence of possible PA problems with energy efficiency investments in firms. A common occurrence in many firms is that they maintain separate budgets for capital investment and operations and are administered by two different –and distant– divisions. Managers in charge of operations cannot easily obtain approval for investments that will reduce energy costs because those investments fail to rise to the top of queue. It is reasonable to hypothesise, therefore, that these PA problems could create nationally significant amounts of energy use that are effectively insulated from energy price signals (at least in the short term). Unfortunately, no quantification of this issue has been undertaken to date.

Howarth *et al.* (2000) have also applied Agency Theory insights to energy efficiency. They state that the practice of capital rationing noted by Ross (1986) in his consideration of small investments in energy efficiency may be understood through the logic of the PA problem.

> By restricting the availability of funds for small investment projects, senior managers are able to reduce the risk that resources will be

> misallocated to activities that are unprofitable, but that might be pursued by rational plant managers whose activities were imperfectly observed. ...Hence rational decisionmaking by both managers and employees leads to an institutional framework in which transaction costs impede the adoption of cost-effective technologies that would generate significant environmental benefits. (Howarth *et al.,* 2000, p. 482).

Sorrell *et al.* (2004) also relate concepts from Agency Theory to end-use energy service markets. In their view, "energy service markets are likely to be characterised by asymmetric information between producer and purchaser and between market intermediaries at different stages along the supply chain". Furthermore, the importance of the asymmetric information depends on the variance in product quality (particularly in relation to energy efficiency), the frequency of purchase relative to improvement in underlying technology and the costs of searching for relevant information. As a result they note that in some circumstances, asymmetric information in energy service markets may lead to adverse selection of energy inefficient goods. Although as with other studies, Sorrell *et al.* make no attempt to quantify the level of adverse selection.

Two conclusions regarding the application of Agency Theory to energy efficiency can be made. First, the principal-agent framework has been widely used in energy efficiency analyses, *e.g.* in tenant-landlord situations. Second, none of the studies have attempted to quantify the impact of PA problems on energy efficiency. This latter point is the focus of this book and is discussed in the following chapters.

METHODOLOGY

This chapter describes the methodology used to identify the existence of Principal-Agent problems in various settings and to estimate the magnitude of energy use affected by PA problems. The methodology described here draws on the concepts presented in Chapters 1 and 2.

Quantifying the energy use affected by PA problems is a significant advance beyond simply identifying market failures and speculating about their impacts on energy use, investments in efficiency, and ability for a market to respond to increases in energy prices. As such, this book provides one of the first attempts to quantify PA problems in energy efficiency markets.

The methodology used in this book relies on the concept of *affected energy use*. That is, energy use that is insulated from the marginal price of energy. Market failures can limit a price signal's influence on energy efficiency investments or energy use management.

Our methodology consists of three steps: (1) Identifying and selecting situations where PA problems potentially exist and evaluating the roles of the parties and their transactions. An analysis of the transactions makes it possible to distinguish between different categories of PA problems; (2) estimating the number of end users affected by PA problems; and (3) estimating the affected energy use for each of the affected populations. In practice, each case study deviates slightly from this approach because of differences in the circumstances behind the market failure, features of the affected population, and the availability of energy data. These deviations will be explained as they arise.

This chapter uses highlights from the television set-top boxes case study to illustrate the steps. A set-top box is an electronic device that receives a video signal and converts it for display on a television. Hundreds of millions of homes in Europe, North America, Australia, and Japan (and elsewhere) contain set-top boxes, although the technologies are slightly different in each country. Each box consumes a small but significant amount of electricity.

Step 1: Identifying and selecting situations where Principal-Agent problems may exist

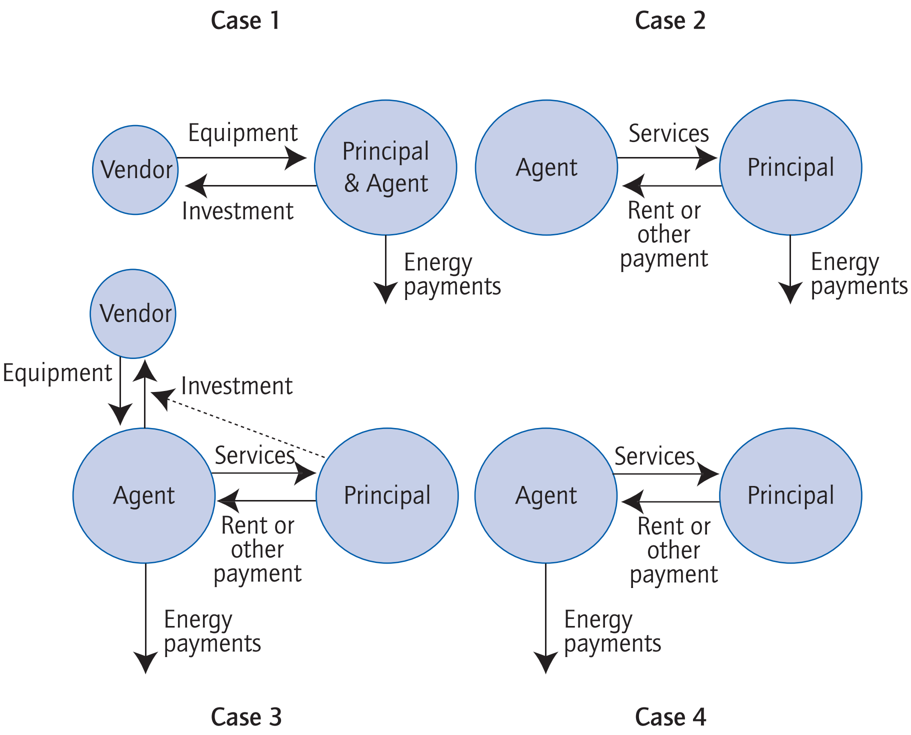
PA problems are not always easy to identify. The first step involves searching for transactions where PA problems may be present. These transactions typically take place between a landlord and tenant, a builder and buyer, or a vendor and owner, although the parties involved may not consider themselves to fall perfectly into one of these categories. There are two distinguishing feature of these transactions. First, they all involve a contractual arrangement between two parties. Second, as a result of the way the contract defines the roles of the two parties, there is market behavior where, on its face, uneconomic allocations of resources take place.

Part of verifying the presence of PA problems involves tracing the transactions between the principal and agent and among other parties. These transactions consist of money, products (such as refrigerators, insulation, and cars); and services (such as rented space, video entertainment, and internet access).

Most Principal-Agent situations can be categorised into four cases depending on the responsibilities of the players. The four cases are illustrated in Figure 4.

FIGURE 4

The four cases of Principal-Agent problems



In *Case 1*, the principal and agent are the same. The same person selects products from a vendor (for example, a furnace, car, or refrigerator), chooses its energy efficiency, and pays the resulting energy bills. In this case there is no PA problem because the principal and agent are the same entity. If no other market failures or barriers are present, the party will make an economically efficient investment in energy efficiency.

A common example of this case is the owner and occupant of a single-family house making decisions regarding the appropriate level of insulation or selecting between refrigerators of differing efficiency.[6]

In *Case 2*, the principal and agent are separate entities. The agent offers a product (such as the services of a building or the sale of an appliance or vehicle) for the principal's benefit. In return, the principal pays a rent or other fee to the agent. The principal must also pay for the energy consumed by the product.

There is a PA problem in Case 2 because the agent lacks incentive to consider energy efficiency and consequent energy use in the choice or design of the product. In this book, Case 2 is called an "efficiency problem". In this context, the market fails to provide adequate information on energy efficiency to the principal.

This is a widely occurring situation, and applies to rental car market, in the apartment rental market (where utilities are individually metered) and in newly constructed buildings. This is the situation in many rented buildings, where the landlord (in this situation, the agent) selects the heating system, level of insulation, and other equipment that determine a building's energy use but the tenant (in this situation, the principal) must pay the energy bill. The landlord's decisions regarding investment in efficiency are insulated from the price signal. That is, an increase in energy prices is unlikely to quickly spur new efficiency investments. Another example exists in newly constructed buildings. In this situation the building contractor makes many energy-related decisions, including the efficiency of the heating system and of the windows, and the building's resistance to air infiltration. Since the energy-efficient alternatives usually increase the cost of construction, the building contractor has incentives to avoid these measures, especially if the measures are invisible to prospective buyers.

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[6] Another market failure, asymmetric information may appear here. The seller of the boxes may know the energy consumption of its products but the buyer does not. This is the case with set-top boxes in almost every country because they do not have energy labels nor is there any comprehensive source of this information. This study did not address the energy affected by other market failures, such as asymmetric information or externalities. A recent study suggested that the energy consumption affected by the climate change externality is very large.

In *Case 4*, the principal and agent are also separate entities. Unlike Case 2, the agent pays for energy consumption. The principal pays only indirectly for energy use as part of the payment for use of the product. The calculation of the payment will depend on the contractual arrangements. In some cases energy costs are invisible to the agent. For example, many apartment buildings provide heat and electricity with no attempt to adjust for variations in energy prices or usage between individual apartment units. This is also the situation in hotel rooms and dormitories. Landlords in commercial buildings with many different tenants frequently prorate the energy costs according to floor areas occupied by the tenants. The common feature of these arrangements is that the principal will not pay for energy consumption directly resulting from the agent's own behavior. As a result, the agent has little incentive to manage energy use in a reasonable fashion. Residents in such buildings may open windows on winter days rather than lower the thermostat setting or they may take exceptionally long showers or fail to undertake even the most basic conservation measures.

In Case 4, the landlord/agent may try to "over invest" in efficiency improvements, that is, install technologies with the highest possible efficiency as a way of off-setting the tenants or hotel guest's unconstrained behaviour. This explains why hotels have more CFLs, automatic light switches or even solar water heaters than the average house.

Case 4 is a PA problem because the principal experiences no financial constraints on usage. In this study, Case 4 is called a "usage problem". It is a market failure in the sense that the agent is unable to make the principal internalise energy costs.

In Case 3, the party that makes energy efficiency decisions does not pay for the energy consumption. (The party's role in influencing the investment decision is shown as a dashed line in Figure 1.) In Case 3 both a usage and an efficiency problem are present. This may seem like an unlikely situation but it does in fact exist for the selection and operation of company cars, a practice that is widespread in Europe and Australia. Some companies permit their employees to select their cars; then the companies pay for fuel consumed on both business-related and personal trips.[7] In the United States, roughly 4% of the population lives in apartments and condominiums where the building owners pay the energy

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[7] Note that this is different to the situation shown in Case 3 where the tenant (principal) pays the landlord (agent) for a service and the *principal* influences the technology selection. In the company-car situation, the company (principal) pays the employee (agent) and the *agent* influences the technology decision. Nevertheless, the important similarity is that in both cases, the *end-user* has an influence over technology selection.

bills. A Case 3 PA problem occurs in this situation when occupants purchase energy-consuming appliances. These occupants select the appliances' level of efficiency but do not pay for their energy consumption. The appliances may be more or less efficient than if the principal had selected them because energy consumption will not enter into the decisions. Case 3 is a market failure in two senses as described in Cases 2 and 4.

These four cases are summarised in the table first presented in Chapter 2.

TABLE 4

The four cases of Principal-Agent problems

	End user can choose technology	End user cannot choose technology
End user pays the energy bill	Case 1	Case 2
End user does not pay the energy bill	Case 3	Case 4

Each potential PA problem was scrutinized to ensure that a PA problem exists. Many cases initially appear to be market failures but, after more detailed examination, fall into the broader category of market barriers. The presence of other market failures or barriers did not preclude the case from further examination.

In each case, this study began by identifying the principal and the agent. The transactions diagrams help make explicit answers to the following questions:

- Who selects, purchases and owns the energy-using technology?
- Who pays the energy bill?
- Who controls operation of the energy-using technology?

In practice, the answers to these questions require careful examination of the contractual relationship and transactions between the parties. It also requires a distinction between the current and the long-run situation. For example, in the long run a tenant will be able to move and perhaps even find new premises where the rent reflects the building's level of energy efficiency. In this study, however, the focus is on the present conditions where these opportunities may not be present (sometimes because of other market failures or barriers).

Each case study also sought anecdotal evidence in the literature and in actual market conditions demonstrating the existence of PA problems. For example, insulation levels or boiler efficiencies should be higher in owner-occupied buildings where no PA problems are present. In other cases, the presence of special product lines (with low-efficiency products) directed towards sales to agents suggests that a PA problem is present.

Our principal criteria for selecting case studies were (1) the ability to clearly identify the principal and agent; (2) the existence of sufficient data to make a credible estimate of affected energy use; and (3) a possibility that the same PA problems exists in several countries. Analyses of the same PA problems in more than one country contributed to their credibility and ease of understanding.

Finally, (4) the "stories" behind the case studies also needed to be easily understood by a non-technical audience.

The case studies drew on data from three entirely independent sources: trade association data for stocks; census data for fraction of homes where others pay the electric bill; and energy consumption data from field measurements.

Information sources also included energy savings potential analyses, trade journal articles, and discussions with experts.

The analysis typically focuses on the energy end-use level – that is, residential refrigerators, space heating in commercial buildings, or water heating. Thus, a key player in the transactions will be the end user, the person who typically derives benefit from the product or service and may (or may not) make decisions regarding purchases and payment of energy bills.

Step 2: Estimating the population of end users affected by the Principal-Agent problem

In Step 2, the population of end users affected by the PA problems in Cases 2, 3 and 4 was estimated. The situations described in Figure 4 above can be translated into a matrix shown in Table 5. The matrix clarifies whether the end user is responsible for selecting the energy-using technology (that is, the level of energy efficiency) and for paying the energy costs. For example, if the end user is able to choose the energy-using technology and pays the energy bill, then the situation resembles Case 1 and no PA problem exists. If the end user cannot choose the technology, then either an efficiency problem (Case 2) or a usage problem (Case 4) occurs – depending on who pays the energy bill.

TABLE 5

Transactions from an end-user perspective

	End user can choose technology	End user cannot choose technology
End user pays the energy bill	Case 1: No PA problems	Case 2: Efficiency problem
End user does not pay the energy bill	Case 3: Usage and efficiency problem	Case 4: Usage problem

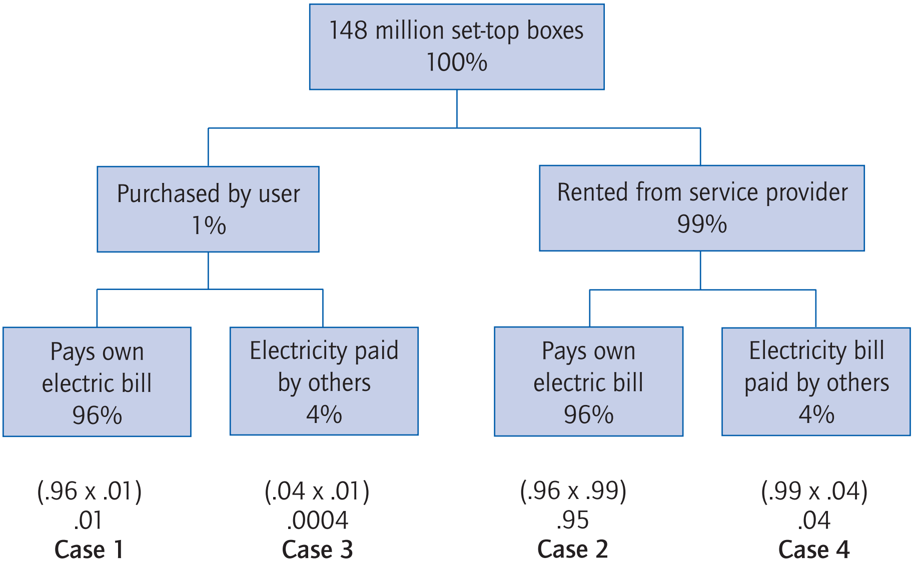
Estimating the population of end users falling into each category is a challenging task because statistics for energy consumption and stock (that is, the number of products) rarely correspond to the categories in Table 5. Perhaps the most important data gap is who bears responsibility for paying energy costs. Government (and private) surveys rarely ask if the purchaser expects to pay the energy bill for a new refrigerator, car, or business premises. Instead, this fraction of the population must be estimated indirectly through combinations of other sources. The availability of appropriate data varies with the end use under investigation.

The analysis of set-top boxes illustrates the kinds of uncertainty that arise in determining the affected population. In summary, set-top boxes (discussed in more detail in Chapter 11) are used to connect televisions to signals broadcast by cable, satellite, and internet service providers. The service providers (such as BSkyB in the UK, Noos in France or Foxtel in Australia) typically require their customers to use boxes that they provide and which come as part of the subscription. These customers fall into either Case 2 or Case 4 because the end users are unable to select the technology or efficiency level of the set-top box. In very limited situations, subscribers in the United States may purchase a set-top box. These customers fall into either Case 1 or Case 3. Figure 5 represents the situation in the United States. The division of the end users into two groups, representing 99% and 1% of the population of set-top boxes, is shown on the second level. These data come from trade associations.

Figure 5

Disaggregation of affected population of end-users for set-top boxes in the United States

Set-top boxes in the United States



The next step in this illustration is to determine how many customers in each group pay for their electricity use? Census data suggest that in about 4% of the homes, the occupants do not pay for electricity. The assumption is that this fraction applies to both homes where the boxes were purchased and where they were rented. This is a reasonable assumption for set-top boxes but would introduce errors for other products. These sub-groups are listed in the lower boxes in Figure 5. The calculations of the fractions for each group are shown at the bottom of the Figure.

Each of the lower boxes in Figure 5 also corresponds to one of the Cases described Table 5. Thus, it is possible to fill in Table 5 with the appropriate populations. This is shown in Table 6. About 141 million set-top boxes in the United States fall into Case 2 – an efficiency problem. The total number of boxes affected by all PA problems is the sum of the populations in Cases 2, 3, and 4, that is, about 147 million. This corresponds to about 99% of the set-top boxes in use.

TABLE 6

Set-top box matrix with relevant populations

	End user can choose technology	End user cannot choose technology
End user pays the energy bill	Case 1: No PA problems 1.5 million	Case 2: Efficiency problem 141 million
End user does not pay the energy bill	Case 3: Usage and efficiency problem 0.06 million	Case 4: Usage problem 6 million

Step 3: Estimating the energy consumption affected by the Principal-Agent problem

The final step involves calculating the affected energy consumption. The affected energy consumption is the amount of energy consumed by the population of end users in each of the cases where a PA problem exists. The total affected energy consumption across all the PA problems is the sum of energy use falling into Cases 2, 3, and 4.

The most common procedure to calculate the affected energy use is to estimate a device’s average energy use and then multiply it by the affected population. This procedure is straightforward in a few circumstances. For example, when calculating affected energy use of retail display coolers in Japan. The average electricity consumption per unit is measured in a laboratory test and the trade associations maintain accurate estimates of the units in service. The analysis for set-top boxes is also straightforward. The devices are nearly identical for all end users, and their energy consumption is almost completely outside the control of the user. This means that boxes that are rented and purchased and where the users do and do not pay for the electricity all consume the same amount of electricity. In this (rare) example the fractions of population shown in Figure 2 also represent the fractions of electricity use, so the total affected energy use is simple to calculate.

In most circumstances, however, the procedures to calculate affected energy consumption are more complex. Detailed data on energy consumption are never plentiful and are rarely reported in the categories required for this kind of analysis. Assuming that devices in each affected group use the same amount of energy can produce additional errors. Energy consumption patterns will vary among the groups for two principal reasons. First, the devices can have different physical characteristics. Second, the devices are also likely to be *used* differently. As a result, the exact procedures used to make these estimates depend heavily on the available information. The individual case studies explain both the sources of the data and methods used to make the estimates of affected energy use.

In summary, the goal of this analysis is to identify the affected populations and provide the best estimate of their approximate sizes. These estimates will have an error margin but they are still useful for policy-making. Sensitivity analyses were conducted wherever possible to increase confidence in the results.

Step 4: Estimating energy savings after removal of Principal-Agent problems

Until this step, our analysis focused on the energy consumption *affected* by PA problems. The final step is to estimate the potential energy savings if the PA problem were resolved. Put another way, how much less energy would have been consumed if the entities responsible for making an efficiency investment and paying the energy bills were the same?

There are two possible approaches to estimating savings. The first approach simply compares efficiencies to parts of the sector where PA problems do not exist. This procedure would be appropriate for the PA problems associated with, for example, domestic water heating. There, a clear baseline exists where a large body of consumers unaffected by PA problems already reveal their preferences.

In some cases, however, the PA problem dominates the market and the energy savings potential are not revealed by other consumers. This is the situation for set-top boxes. To calculate savings in these situations, this study further assumed that this single entity behaves in a rational manner, that is, it reasonably balances first costs against savings in future energy expenses.

In practice, the procedure to estimate potential energy savings requires detailed information about the population of existing equipment, their efficiencies, the patterns of usage, costs of various efficiency improvements and other factors affecting the cost-effectiveness of investments. This information is similar to that needed to create a "supply curve of conserved energy" (Meier, 1982) and other "bottom-up" assessments of conservation potentials for a region. All developed countries (and many less developed countries) have undertaken these estimates of energy-savings potential (Meier and Wright, 1981). Most of these studies relied on prototypes or representative cases to estimate energy savings and cost-effectiveness for different improvements. The savings potentials derived from the prototypes are then used as the basis for region-wide energy savings. These potentials studies assume – though most often implicitly — that PA problems will be overcome.

The procedures to estimate potential savings outlined above do not typically take into account several market conditions. The most important factors determining potential savings are described below.

Continued presence of other market failures. The PA problem may be one of several market failures affecting investment and operating decisions in that particular end use. Second-order PA problems, that is, transactions with third and fourth parties, may also influence investment and operating decisions even though they are not directly addressed in these analyses. Externalities will still apply even after a PA problem is solved. The Stern Report noted that climate change is the largest market failure in the world and it applies to all non-renewable uses of energy. This study ignored other failures when estimating potential energy savings.

Energy savings converted into increased welfare. Investments in cost-effective efficiency measures create wealth because they have a net present value. Firms will invest this wealth in their businesses in order to increase revenues, reduce costs, or return profits to shareholders. Consumers will act in a similar fashion, that is, consume or save. These actions will naturally lead to additional energy use, though much less than saved from the original energy-savings action, rarely more than 10% of the energy saved.[8] The additional energy use caused by re-spending was not subtracted from the potential energy savings.

Alternatively, consumers will convert their increased wealth into greater amenities, such as warmer homes in the winter and cooler homes in the summer. In transportation, consumers might choose to drive more efficient autos greater distances (although there is little evidence suggesting that they do). Consumers

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[8] This is sometimes called the "rebound" effect. However input-output analyses have demonstrated that the effect is generally small on both macroeconomic and microeconomic levels.

might purchase a larger, more efficient, refrigerator, or purchase a brighter compact fluorescent light and operate it more hours than the incandescent light that the fluorescent replaced. This phenomenon is confined to a relatively few end uses and is generally a small effect. The conversion of energy savings into increased amenities is especially true where the levels of service were low to begin with. In Japanese homes, for example, the average winter-time temperature has risen in the last twenty years without a corresponding increase in energy use because a large part of the benefits from efficiency improvements have been converted into higher levels of thermal comfort. The potential energy savings therefore depend on the levels of service assumed before and after the efficiency improvements. When estimating savings potentials, this study assumed that consumers did not convert the saved energy into increased amenities.

These are, to be sure, "heroic" assumptions. Nevertheless, they establish an upper boundary and, with present use as a lower boundary, establish the range of potential energy savings.

Conclusions

This chapter explains the general approach to estimate the amount of energy consumption that is affected by PA problems. This is a significant advance beyond simply identifying market failures and speculating about their impact on energy use, investments in efficiency, and ability for a market to respond to increases in energy prices.

A key step in the methodology is identifying the four different relationships that can exist depending on the party responsible for making energy-efficient investment decisions and the party responsible for paying for the energy consumption. Two distinct types of PA problems emerged, an "efficiency" problem and a "usage" problem. Minimising these different types of PA problems will need separate policies; however, the two forms will be combined for purposes of describing the overall affected energy use insulated from energy prices.

One obstacle to widespread application of this methodology is the absence of data collected in a suitable form. This methodology requires, for example, estimates of the populations of energy-using devices where the purchaser does not pay for their energy consumption. The governments of Australia (Productivity Commission, 2005), the United States (Executive Office of the President of the

United States of America, 2007), and perhaps others have adopted policies that require documentation of market failures before new regulations can be implemented. As this methodology demonstrates, data are rarely collected in a form that will easily permit the determination of the PA problem's size and significance.

The next chapters present the case studies that apply this methodology to specific sectors in several countries.

Commercial sector: case studies

PRINCIPAL-AGENT PROBLEMS IN THE COMMERCIAL OFFICES SECTOR

This chapter focuses on Principal-Agent problems in the commercial offices sector. PA problems, defined in Chapter 1, occur when economic inefficiencies arise during an economic exchange between two parties (a "principal" and an "agent") who have different goals and different levels of information. Three case studies in Japan, the Netherlands, and Norway investigate and quantify PA problems in each country in commercial offices. Before turning to the case studies, this chapter brings the theoretical discussion of Agency Theory applied to energy efficiency (provided in Chapter 2) one step further by applying the Agency Theory to the specific characteristics of energy efficiency in the commercial offices sector.

Agency Theory and energy efficiency issues in the commercial offices sector

Using the same dimensions of Agency Theory from Chapter 2, Agency Theory can be applied to the Commercial Offices sector. A summary is presented in Table 7.

Identifying the Principal and the Agent in the commercial offices sector

Figure 6 illustrates the transactions between principals and agents specific to the commercial office sector.

In the commercial offices sector, PA problems occur when the person choosing the energy equipment for the office space is not the same as the person paying the energy bill. The principal is the tenant of the office who pays the agent for access to a facility, but who – in most cases – does not buy the energy technology. The agent, on the other hand, is the office owner who chooses the technology but does not pay the utility bill.

Figure 6 illustrates the transaction between the different actors.

TABLE 7

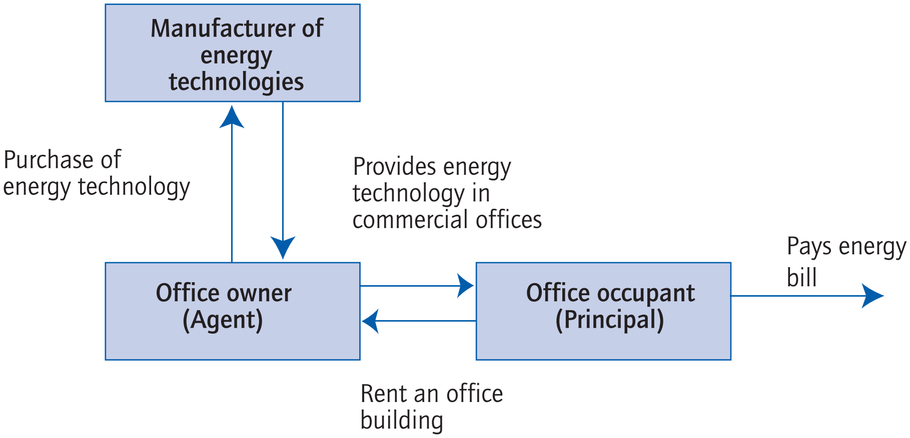
Dimensions of Agency Theory applied to the commercial offices sector

Dimension	Standard application of agency theory (Owner-Manager)	Energy efficiency context in the commercial offices sector
Unit of analysis	Relationship (and contract) between owner (principal) and manager (agent)	Relationship (and contract) between landlord (agent) and office occupant (principal)
Problem domain	Relationships in which the principal and agent have different levels of information and partly differing goals	Relationships in which the principal and agent have different levels of information about energy efficiency and partly differing goals
Goal orientation of the actors	Goal conflict between principal and agent. Owner's goal is to maximise returns. Manager's goal may be to limit work levels required	Goal conflict between principal and agent. Landlord's goal is to maximise returns/minimise capital costs. Tenant's goal is to limit energy costs
Key objective	Principal-agent relationships should reflect efficient organisation of information to maximise economic efficiency	The energy user *and* energy technology selector should both consider energy costs
Human assumptions	Self-interest Bounded rationality Individual autonomy	Self-interest Bounded rationality Individual autonomy
Organisational assumptions	Partial goal conflict Economic efficiency as the criterion Information asymmetry Agent delegated the task by passive owner principal	Partial goal conflict Energy efficiency as the criterion Information asymmetry Agent provides accommodation to tenant (principal)
Assumption about the source of problem	Contract inadequate	Contract inadequate in that is set up in a way that at least one party that is involved in energy-related decisions is insulated from the energy price
Implications of inefficient relationship/ contract	Adverse selection Moral hazard Split incentives	Adverse selection Moral hazard Inefficient energy use

There is a financial relationship between the manufacturer and the office owner, because the office owner purchases the technology from the manufacturer. There are two relationships between the office owner and the office occupant: the office occupant rents the office building and the office owner provides the occupant with the energy technology. In the case where the owner of the building is also the user, then the principal and agent are the same person.

FIGURE 6

Schematic presentation of the Principal and Agent in commercial leased office transactions



Identifying Principal-Agent problems in the commercial office space sector

Identifying PA problems in the commercial office space sector involves searching for transactions where PA problems may be present. This requires answering two questions: Who pays the energy bill? And who makes decisions on energy saving measures?

Using the same table from Chapter 2, PA problems in commercial offices can be categorised into four cases, depending on who bears the responsibility for paying the energy bill and who makes decisions on energy saving measures.

TABLE 8

Principal-Agent problems from the end-user (tenant) perspective

	End user can choose technology	End user cannot choose technology
End user pays the energy bill	Case 1: No problem	Case 2: Efficiency problem
End user does not pay the energy bill	Case 3: Usage and efficiency problem	Case 4: Usage problem

In Case 1, the energy end user (the owner or tenant) chooses the technology and pays the energy bill. In the Netherlands, 60% of the commercial offices fall into this category. Two-thirds of this group of offices is private property, which means that the end user of energy is also the owner of the office space. One-third of this group is comprised of tenants that rent their office space. There are no PA problems in this case. Both groups of office users have incentives to actually save energy, because they are directly affected by the consequences of increased energy use.

In Case 2, the energy end user (the tenant) does not choose the technology, but pays the energy bill. An efficiency problem arises, because the person paying for the energy is not the person choosing the technology. This group will vary according to the particular circumstances of the country. In the Netherlands, for example, the case study estimates that 40% of the total commercial office stock falls into this category. The owner of the building, who does not pay the energy bill, does not see energy costs increasing with inefficient energy use. The building owner has the incentive to minimise capital and maintenance costs, and does not likely have any incentive to invest in energy saving measures. The technology buyer will generally choose among the cheapest and often not the most energy-efficient options. This leads to a situation where even cost-effective energy saving measures are not carried out, because from the owner's perspective these measures impose costs for which they see no beneficial return.

In Case 3, the end user of energy chooses the technology, but does not pay the energy bill. In purchased offices this situation would not occur. In the case of a rented office this situation implies that the owner of the building pays the energy bill while the tenant of the office space makes the investment decisions. In practice this situation will seldom occur and therefore is not covered in this study.

In Case 4, the end user of energy does not choose the technology or pay the energy bill. In purchased offices this situation would not occur. In rented offices this implies that the tenant neither pays the energy bill nor is allowed to make energy efficiency investment decisions. Cost effective measures might be carried out, because the owner of the building tries to optimize energy costs. On the other hand, the end-user of energy will not have an incentive to lower energy use because higher energy costs are not directly passed over to them.

In Case 1 and Case 4, the building owner has an incentive to consider future energy costs when choosing a building energy system so that the total of life-cycle costs is minimised. However, in Case 2, the building owner might potentially choose a building energy system with the least initial cost, without taking future energy costs into consideration. In this case, the chosen energy solution might be the best option for the building owner, but not optimal for the user. The hypothesis to be studied is whether or not the office buildings categorised in Case 2 might use more energy because of this split-incentive problem, than those categorised in Case 1 and Case 4.

Although the scenario and figures illustrate the situation that is true in all three case studies, the case studies will show that there are nonetheless important differences between the countries. Typically, energy saving is not an important issue in the operational management of companies in the service sector in the Netherlands. First, the energy costs are just a small part of the total operating costs of the company (about 1%). Secondly, most end users of energy rent their office space and are not responsible for making decisions on energy saving measures. This situation occurs in Case 2 and Case 4. Case 4 is not relevant for the Dutch situation, as it seldom occurs. Therefore, the main focus of this study will be on the split-incentive problem of Case 2, which covers about 40% of all office space in the Netherlands.

In Norway on the other hand, owner-occupied buildings are only a fraction of the total office space. The potential problems described above are thus highly relevant in a Norwegian context.

The case studies are presented next.

ENERGY USE AFFECTED BY PRINCIPAL-AGENT PROBLEMS IN JAPANESE COMMERCIAL OFFICE SPACE

This case study investigates the size of potential Principal-Agent problems in Japanese commercial office space.

Energy use in Japanese commercial office space and energy-efficient policies

Energy use in commercial offices in Japan

Japan is a resource poor country, which is nevertheless industrialised, developed, and highly urbanised. As such, the country is highly dependent on foreign imports. It imports about 19 598PJ/year, for a total final energy consumption of 16 015 PJ (Energy Balance Statistics of Japan 2005).

Energy use in the Commercial Sector in Japan represented 13.2% of total energy use in 2005 (The Energy Conservation Center Japan 2007). Commercial office space is the second-largest end-use of energy in the commercial sector in Japan. As shown in Figure 7, office space accounts for 18% of total commercial sector energy use in Japan, second to retail store consumption of 24%.

Total energy use in the commercial sector in Japan has increased and is expected to continue to grow. Figure 8 shows that total energy use has been increasing at an annual average rate of 2.5% since 1975. Electricity consumption from the increasing number of electric appliances, and increasing air conditioning demand has driven this growth. Growth in the tertiary sector relative to the industrial sector, and in the use of electric appliances, is expected to contribute to continued growth of commercial sector energy use.

FIGURE 7

Energy use share by business type in commercial sector (2005)

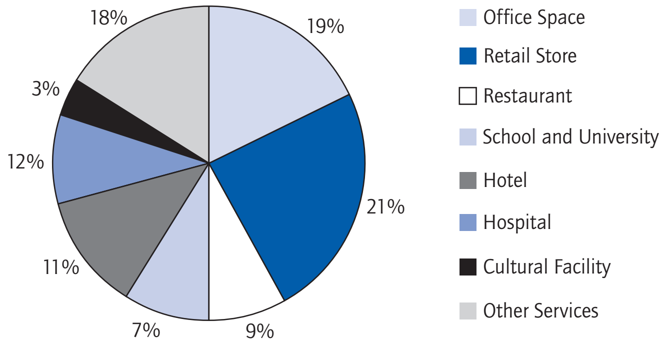
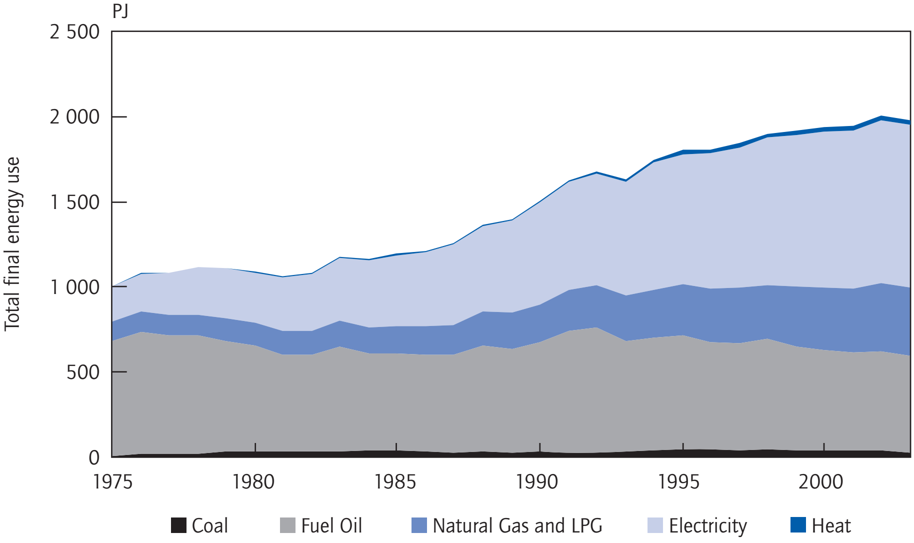


FIGURE 8

Final energy use of commercial sector by fuel source (1975-2003)



Energy efficiency policies

Japan has long been sensitive to energy security and familiar with energy security and energy efficiency policies because of its historic dependence on foreign oil. For example, in 1979, Japan implemented the Energy Conservation Law that imposed energy efficiency requirements on certain factories and workplaces. By 2005, the regulation covered the commercial building sector and a wider range of factories.

The law requires designated businesses to make planned energy conservation improvements and provide annual reports on their progress. Certain businesses must appoint an energy manager and the most energy-consuming factories must also achieve a 1% annual reduction in energy use. METI has begun random inspections of factories to determine their compliance with the Law and non-complying businesses must submit compliance plans or the government publicises their name.

The most important measure in the commercial/residential sector is the Energy Conservation Law to improve appliance energy efficiency. Under this law, product manufacturers must comply with the "Top Runner Scheme" standards, which currently cover 21 product categories (see discussion in Japan Vending Machine case study). The government also initiated the voluntary appliance labelling programme, the retailer assessment system and the comparative five-star rating labelling programme to facilitate the market diffusion of existing energy-efficient appliances.

Japan instituted building codes relatively early in the late 1970s. The country later strengthened the code in 1980, 1992 and 1999. Owners of newly constructed or renovated buildings 2 000 m^2 or larger must report energy efficiency measures included in their buildings to the government. Computer energy management tools, including the Home Energy Management System (HEMS) and the Building Energy Management System (BEMS), also facilitate energy conservation in the building and residential sectors. The HEMS is currently being field tested, and the BEMS is already in the market. The Energy Conservation Center (ECC) also performs on-the-spot energy audits of factories and buildings free of charge. From 1997 to 2006, ECC completed a total of 4 389 audits, including 1 259 for type 1 designated factories, 893 for type 2 designated factories, and 2 237 for non-designated factories. To perform the audit, the Energy Conservation Center sends two specialists to the factory. At the end of the audit, ECC provides recommended energy efficiency measures. ECC checks the effect of the audit one or two years later.

Financial support measures in the commercial buildings sector, include the allocation of funds to promote the introduction of high-efficiency energy systems in houses and buildings. In the 2007 government budget, 24.2 billion yen were allocated to such programmes. Tax incentives are also in place to support projects that promote energy efficiency. The first project is the Energy-Saving Promotion Project for Buildings which supports repair projects contributing to improvement in energy-saving performance (ESCO/ESP projects only). The second project is to promote the efficient use of energy which includes the acquisition of energy conservation facilities, including remodeling and updating of existing facilities. For the specified facilities and ESCO projects, lease and rental of facilities fall within the scope of this funding.

The government has also used soft instruments including advertising campaigns and voluntary training programmes to facilitate the diffusion of energy-efficient products into the market.

TABLE 9

Outline of present and future energy efficiency policies in Japan

Sector	Policy name	Energy conserved (crude oil equivalent)
Residential / commercial	Improvement of efficiency with Top-runner restriction	5.4 million kl
	Improvement of energy efficiency in houses and other buildings	17.2 million kl
	Accelerated expansion of highly efficient equipment	3.5 million kl
	Reduction in standby power consumption	0.4 kl
	Popularisation of HEMS & BEMS	2.2 million kl
	Exhaustive energy management by Energy Conservation Law	0.7 million kl
	People's effort	2.2 million kl
	Subtotal	31.6 million kl

Source: ECCJ, 2006.

Table 9 shows estimates of the energy saved in the residential and commercial sector from present and future energy efficiency policies. Because of the existence of active energy efficiency policies, Japanese consumers are aware of the importance of energy efficiency. As a result, there is presumably less information failure in Japan than in other countries.[9]

The size of Principal-Agent problems

Data collection

This section examines the energy consumption levels of the commercial office sector in Japan. This analysis is based on a literature review and a database study. Differences in energy consumption levels among the four different cases could establish evidence of PA problems in the Japanese commercial office space sector. A comparison of the energy consumption is made on a per floor area basis.

The Building-Energy Manager's Association of Japan (BEMA) performed a multivariate analysis of energy consumption of office space in 1995 (The Building-Energy Manager's Association of Japan, 1995). The analysis is based on a dataset of annual energy consumption of about 2000 commercial buildings across the country from 1988-92. The analysis separates the amount of energy use[10] according to the ownership of mainframe computers, the number of floors in the building, and the ratio of rentable office space floor area to total floor area of the building. A summary of the results is shown in Table 10. The table shows that the higher the ratio of rentable office space floor area, the higher the per-square metre energy consumption. This result can be regarded as evidence of PA problems.

BEMA also conducted a survey of the energy consumption of 860 office buildings across the country in 2002 (The Building-Energy Manager's Association of Japan, 2002). The report compares the energy consumption of office buildings per square metre according to various building attributes. Figure 9 shows one of the resulting comparisons of per square metre primary energy consumption between owner-occupied and rental office space. In the former case, a building owner occupies the entire floor; in the latter case, a tenant occupies all or part of a floor.

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[9] http://www.eccj.or.jp/index_e.html.

[10] Normalised using raw energy data.

TABLE 10

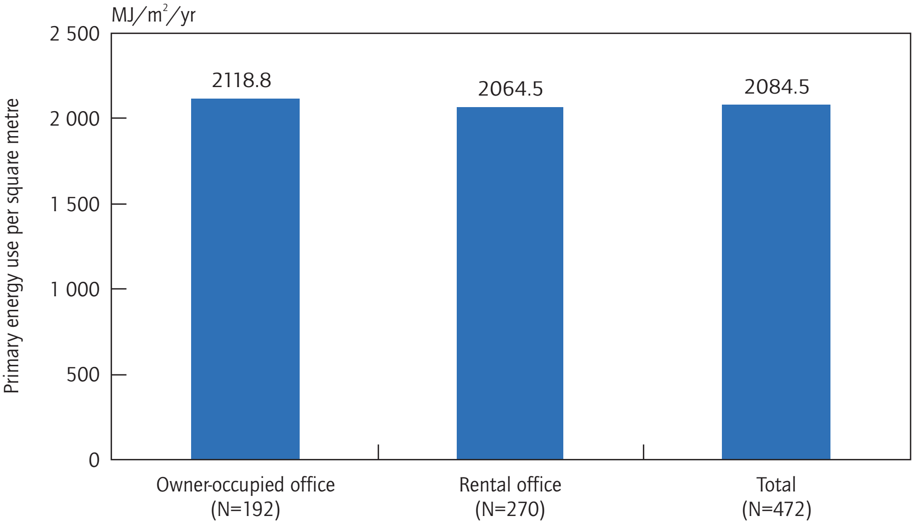
A multivariate analysis result of office space energy consumption (BEMA1)

Year	Number of sample	Average primary energy use per square metre (Mcal/m²/yr)	Ownership of mainframe computers (Mcal/m²/yr)	Floor number of building (Mcal/m²/yr)			Ratio of rentable office space floor area (Mcal/m²/yr)				Other variation factors (Mcal/m²/yr)
				Less than 5	6 to 10	More than 11	Rental: 0% Owner-occupied: 100%	Rental: 1-49% Owner-occupied: 50-99%	Rental: 50-99% Owner-occupied: 1-49%	Rental: 100% Owner-occupied: 0%	
1989	442	487.1	72.5	-4.5	-4.2	40.9	-8.3	-9.2	2.9	7.1	58.4
1990	253	469.8	73.3	-2.3	-3.7	55.9	-8.8	-10.3	2.6	7.1	24.9
1991	456	453	71.7	-4.0	-3.8	50.1	-8.7	-11	2.7	6.5	18.2
1992	407	416	72.0	-10.9	-3.4	40.7	-8.0	-10.3	2.8	7.1	-5.2

The figure shows that there is little difference in the per square metre energy consumption between the owner-occupied and the rental office on a MJ/m^2/year basis. However, this data set does not isolate the ownership factor from other influential factors.

Figure 9

Difference in per square metre energy use between owner-occupied and rental office space in Japan



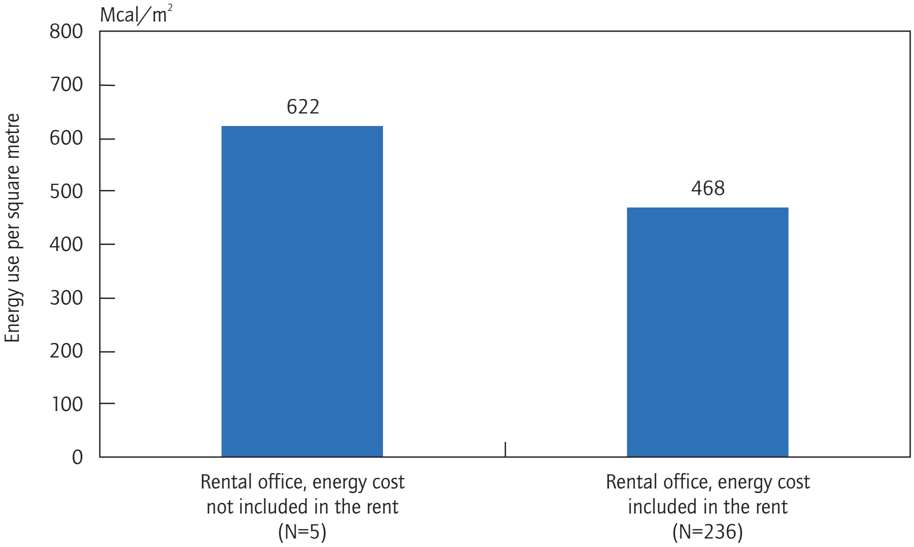
Source: The Building-Energy Manager's Association of Japan, 2002.

This study also analysed rental office data to find out whether the energy bill payment method influences the energy consumption of the building. This study used a building energy dataset that CRIEPI maintains for a government-funded research project (Ministry of Economy Trade and Industry 2004). This data set was developed based on a survey conducted by CRIEPI in 2004 for commercial buildings across the country. It contains energy-related building attribute data as well as monthly energy consumption data of 1 764 commercial buildings. Data for 439 rental office buildings are included. The building attributes included in the survey include floor area, building location, share of floor area by floor usage (*e.g.*, office, store, hotel and residence), ownership of energy-using facilities, energy billing method, type of air-conditioning system, and business hours per day, among others.

Using the dataset of 439 rental office buildings, this study made a comparison between the energy use per floor area of two types of rental office buildings: rental office space where energy costs are included in the rent (Case 4) and rental office space where energy costs are not included in the rent (Case 2). Here the comparison of the energy use per floor area is made on a primary energy basis. As shown in Figure 10, after excluding invalid samples, the comparison shows that energy use per square metre is about 33% higher in energy-cost-not-included rental office space than in energy-cost-included rental offices. However, these values were calculated by averaging observed values of 5 valid samples for the energy-cost-not-included rental office space and of 236 valid samples for the energy-cost-included rental office space. The limited sample size makes it difficult to assert any empirical evidence of a gap in energy use between the two types of rental office buildings.

FIGURE 10

Difference in per square metre energy use of rental office space between energy-cost included and energy-cost not included



Source: Ministry of Economy Trade and Industry, 2004.

Data on nation-wide commercial building stock is available from the database developed and maintained by IEEJ/EDMC (2005), which gives time-series data of energy consumption by business type and by fuel source, and building stock by business type. The EDMC data book (The Energy Data and Modeling Center, 2001) also gives more detailed end-use energy data of various types of commercial buildings. Since no database on building stock by ownership of building and by energy bill payment method exists, this study used survey data (NOPA, The Energy Conservation Center Japan, 2007).

Description of the results

There were 460 million square metres of commercial office space in Japan in 2005. Of these, estimates show that approximately 18% is owner occupied (*i.e.* 83 million square metres) and approximately 60% is rented (*i.e.* around 276 million), (The Energy Data and Modeling Center, 2005). According to reports on energy conservation in commercial buildings (The Energy Conservation Center Japan, 2007), 71% of the rental office space does not pay the energy bill, while in 29% of rental office space the tenant pays the energy bill.

Based on these numbers, the tenant does not pay the energy bill in approximately 196 million square metres of commercial office space. The tenant pays the energy bill in 80 million square metres of commercial office space. These results are summarised in Table 11.

TABLE 11

Estimated floor stock of commercial office space for Cases 1-4

	End user can choose technology	End user cannot choose technology
End user pays energy bill	Case 1: No problem Owner-occupied office: 83 mil. m^2 (18% of total floor area)	Case 2: Efficiency problem Rental office, energy costs not included in the rent: 78 mil. m^2 (17%)
End user does not pay energy bill	Case 3: Usage and Efficiency problem 0%	Case 4: Usage problem Rental office, energy costs included in the rent: 198 mil. m^2 (43%)

To estimate the energy use of commercial office space for each case, this study multiplied: 1) the total floor area of the office building stock (460 million square metres); 2) the per square metre primary/site energy consumption of office buildings (1.67GJ/m2/yr[11] as primary energy, 0.78GJ/m2/yr[12] as site energy); and 3) the fraction of office buildings for each case.

The estimated energy use of commercial office space affected by PA problems is shown in Table 12. The analysis in the previous section provided little empirical evidence of a barrier. However it allows an estimate of PA problems from 0% to 3% of the total commercial final energy use, or 0%-0.4% of the total of national final energy use, which corresponds to 61PJ/yr[13] as site energy and 131 PJ/yr[14] primary energy.

TABLE 12

Estimated energy use of commercial office space for Cases 1–4

	End user can choose technology	End user cannot choose technology
End user pays energy bill	Case 1: No problem Primary energy: 138.3 PJ Site energy: 64.6 PJ	Case 2: Efficiency problem Primary energy: 131 PJ Site energy: 61 PJ
End user does not pay energy bill	Case 3: Usage and Efficiency problem 0PJ	Case 4: Usage problem Primary energy: 330.1PJ Site energy: 154.3PJ

Analysis and implications

Analysis and policy recommendations

The Japanese commercial office space case study stands as a good illustration of the national context's influence. Because Japan is resource poor, there has been a history of long national awareness of energy security. This allowed room for significant early energy efficiency policies and improvements.

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[11] 465kWh/m^2/yr.

[12] 218kWh/m^2/yr.

[13] 16.8TWh/yr.

[14] 35.7TWh/yr.

The combination of the early imposition of building codes and audits reinforced this awareness. Today building energy policies contribute 31.6 million kl of oil equivalent of energy savings. This study estimates that PA problems affect about 3% of the total electricity use in the sector, which still represents 60.5PJ of energy-saving potential.

Limitations of the study

The above results show some evidence of PA problems in the Japanese commercial office space sector, however the data has limitations. A more intensive survey of commercial office buildings would be needed to determine the precise size of the PA problems.

Conclusions and recommendations

This study quantifies energy use affected by the principal-agent barrier in Japanese commercial office space. By examining transactions between building owners and tenants, this study found that, of three types of office buildings, owner-occupied, energy-cost-included rental, and energy-cost-not-included rental office, only the energy-cost-not-included rental office is affected by PA problems. This study finds evidence of PA problems, but, because of data limitations, this study estimates the energy use affected by PA problems to range from zero to 60.5 PJ or (16.8TWh/yr) on a primary energy basis, which accounts for 1.5% of total national electricity consumption in the sector (APEC, 2006).

PRINCIPAL-AGENT PROBLEMS IN COMMERCIAL OFFICES IN THE NETHERLANDS

This case study attempts to quantify Principal-Agent problems in commercial offices in the Netherlands. It also analyses whether PA problems cause higher energy use in rented commercial offices[15] compared to purchased offices in the Netherlands.

Energy use in commercial offices in the Netherlands and energy efficiency policies

Energy use in commercial offices in the Netherlands

Average primary energy use in Dutch offices was 1 435 MJ/m^2 in 2003, comprised of 679 MJ/m^2 of natural gas and 756 MJ/m^2 of electricity (SenterNovem, 2004).[16] In the Netherlands, a significant part of the commercial office sector is for rent (in 2003 this share was 61%).

Energy use in commercial and public offices increased between 1980 and 2000. According to Joosen *et al.* (2007), primary energy use in the tertiary sector increased from 369 PJ in 1995 to 459 PJ in 2005. Both natural gas and electricity consumption has increased since 2002. According to the Energiebesparings Monitor of SenterNovem, an increase in energy use per square metre has contributed to this increased energy use. This is partly due to the fact that offices have been installing more mechanical cooling systems that consume more electricity (SenterNovem, 2004).

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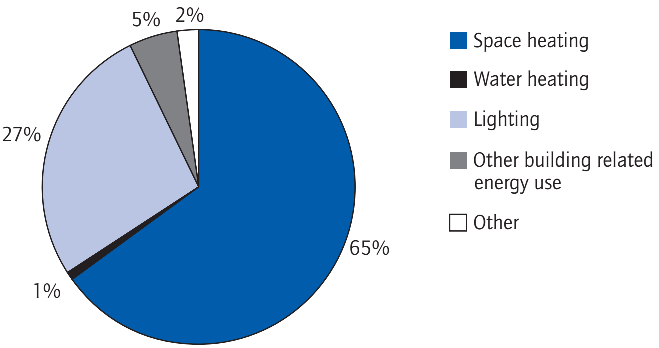
[15] The commercial offices included in this case study include the trade and services, banking and insurance, transport and communications, business services and automation sectors. This study defines an office as a building where the activities conducted focus on information processing, not on the manufacturing and/or storage of goods. Schools, hospitals and governmental offices are not included in our definition of the commercial office segment.

[16] These numbers are based on a small selected group of companies that delivered energy figures in 2002 and 2003.

Energy use in office buildings can be separated into building related (88%) and non-building related (12%) use. Almost 65% of the building-related energy used in offices is used for space heating, followed by 27% for lighting and 1% for water heating. Figure 11 shows building related energy use. Figure 11 does not include energy use of office appliances.

FIGURE 11

Building-related energy use in Dutch offices



Source: SenterNovem, 2004.

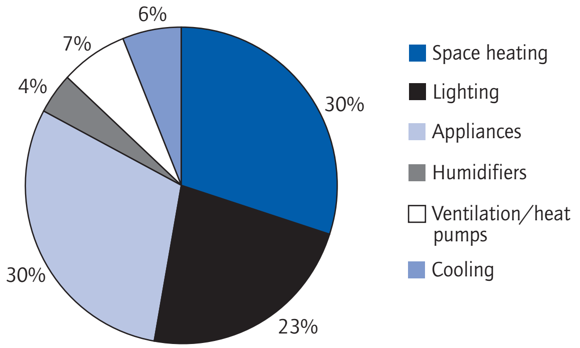
Non building-related energy consumption includes electricity used by computers, telephones, printers, copiers and faxes (Van den Ham, 1996). These functions together make up 20% of the total electricity use in office buildings. Computers consume the largest share of electricity, followed by printers and copiers. Figure 12 shows building and non-building related energy use together.

65% of the total energy used in office buildings is used for indoor climate control. This includes energy used for gas for space heating, electricity for cooling and reducing humidity, electricity for mechanical ventilation, electricity or gas for humidifiers, and electricity for transport of heat and cold by means of water (pumps).

Gas for space heating comprises the largest share of energy consumption in Dutch offices. Cooling and mechanical ventilation also consume a significant portion of the electricity used for climate control (Van den Ham, 1996). Approximately 67% of offices are equipped with a cooling system and 75% have mechanical ventilation.

FIGURE 12

Share in primary energy use of building and non-building related energy consumption activities in Dutch offices



Source: SenterNovem 2000.

Lighting also consumes a significant share of energy in offices (27%). In existing office buildings, the light intensity is generally between 15 and 25 W/m^2. For new buildings, the light intensity is somewhat lower, between 10 and 15 W/m^2 (Van den Ham, 1996).

Energy efficiency policies

Several policies in the Netherlands target energy use in commercial office buildings. In December 1995, the Netherlands implemented the Energy Performance Standard (EPN) for new and major-renovated non-residential buildings. The policy's goal is to achieve 15%-20% in energy savings in comparison with previous building practices.

The EPN requires that the energy demand of a new building be below the Energy Performance Coefficient (EPC), a measure of energy efficiency which is met using cost-effective measures. Because the EPC must be completed to obtain a building permit, the EPC calculations must be done during the design phase. The EPC for offices was 1.9 when it was first introduced in December 1995. The government tightened it to 1.5 in January 2003. The energy agency SenterNovem monitors the policy, and has conducted many studies to evaluate the results and impacts of energy performance standards of buildings in the Netherlands.

The Environmental Management Act, introduced in 1993, covers most of the companies in the service sector and brings together all previous environmental acts into one centralized and simplified Act. It encompasses air pollution, waste and soil management and water issues, among others. Under this Act, administrators can implement specific rules and make bylaws to improve their building's energy efficiency.

Financial support for energy-saving measures for-profit companies is available through the Energy Investment Deduction scheme (EIA). The EIA, effective January 1997, tax deductions to firms investing in specific energy-saving technologies. The benefits of the EIA can vary year to year but with a tax deduction of 55% the net financial benefit to companies is about 18% (SenterNovem, 2004).

The size of Principal-Agent problems

Data collection

This study used several sources to quantify the share of commercial offices represented by PA problems. The results are presented below. Data on the amount of office space is available, but the associated energy use is not widely addressed in the current literature.

This study used major survey studies for the collection of data, including the annual survey of Dutch offices for the ownership status of commercial office space in the Netherlands (Bak, 2003, 2004). This data is discussed in further detail below. For Dutch commercial offices energy consumption, this study used the Energy Savings Monitor of SenterNovem (2004). For information on who pays the energy bill, this study used a sector study on office-using services by Van den Ham (1996).

The literature used in this case study supports the hypothesis that investments in energy efficiency are hindered when tenants do not make investment decisions but pay the energy bill. This leads to an efficiency problem as represented by Case 2. Consequently it is expected that the energy use in rental offices is higher than in owned offices.

In order to quantify the effect of split incentives that might occur in the rented office space, data on energy use in rental and purchased offices is needed. In other countries (*e.g.* Norway) it is known that the energy use in Case 2 situations is indeed higher in rental offices than in purchased offices. Unfortunately, Dutch statistics do not report the expected difference between energy use in rented offices and purchased offices. There are no studies available to support the assumption that rental offices consume more energy than purchased offices in the Netherlands. Therefore, this study assumed that rented offices have the same average energy use per square metre as owned offices.

Table 13 presents the characteristics of the office market in the Netherlands from 1995 to 2003. The overall office stock and actual used office space is measured in Rentable Square Feet (RSF), the area for which rent is charged, and this represents about 86% of the gross rentable square feet. This area may include a share in building support and common areas such as elevator lobbies, building corridors, and floor service areas. The rentable square feet of commercial offices increased from 32 million square feet in 1995 to over 41 million square feet in 2002 (Bak 2003), approximately 4% per year.

Commercial office buildings can either be rented or purchased. In the rental market, private individuals or investment companies/project developers are the users. In 1993, 54% of the commercial offices stock was rented. Ten years later, in 2003, this share grew to 60% (Bak, 2004). In purchased offices, the owner is also the user. Purchased office space declined from 46% in 1993 to 40% in 2003.

TABLE 13

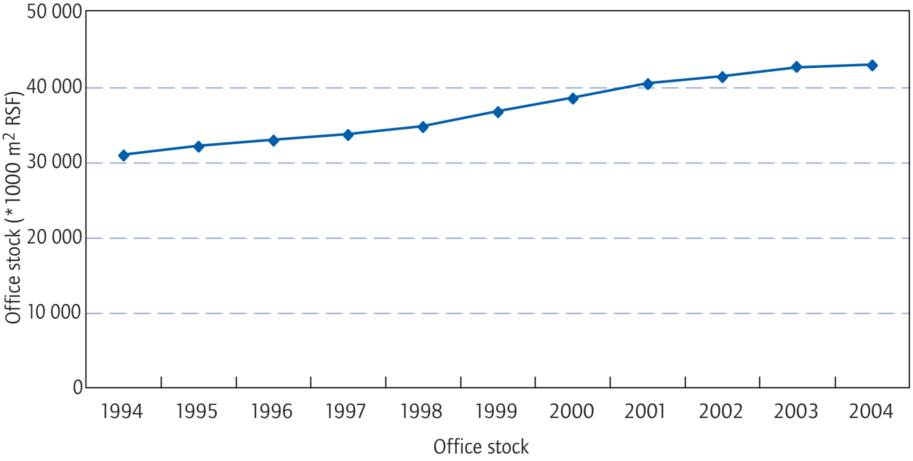
Characteristics of the Dutch commercial office market

Year	Office stock (1000 RSF)	Used office space (1000 RSF)
1995	32.015	29.571
1998	34.681	32.897
1999	36.429	34.271
2000	38.496	35.855
2001	40.229	36.649
2002	41.428	36.667
2003	42.712	n.a.

Source: Bak, 2003, 2004.

FIGURE 13

Development of commercial office stock in the Netherlands measured in square metres



Source: Bak, 2005, and www.vastgoedmonitor.nl.

The share of purchased office space shows large disparities at the local level. For example, in Utrecht 65% of the office space is for rent, while the share of purchased offices in Rhenen is only 8% (Bak, 2004). People are generally more willing to rent office space than to purchase it. Statistics show that a large part of the new buildings being constructed are for rental use, as shown in Figure 14.

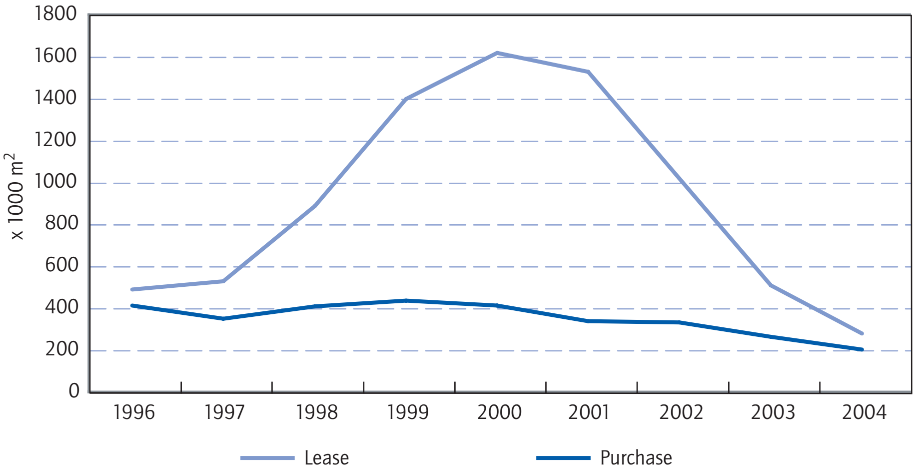
In 1993, 54% of the offices were rented and 46% were purchased. The share of rented offices increased to 60% in 2003 (Bak, 2005). This trend is expected to continue. This study expects Principal-Agent problems to arise in this office leasing segment.

Description of the results

Table 14 presents the classification for PA problems in the commercial office space sector. The table shows the share of commercial office space and related square metres per case. When data is available the shares are further split up into owned and rented offices.

FIGURE 14

New-build offices and their type of ownership



Source: Bak, 2004.

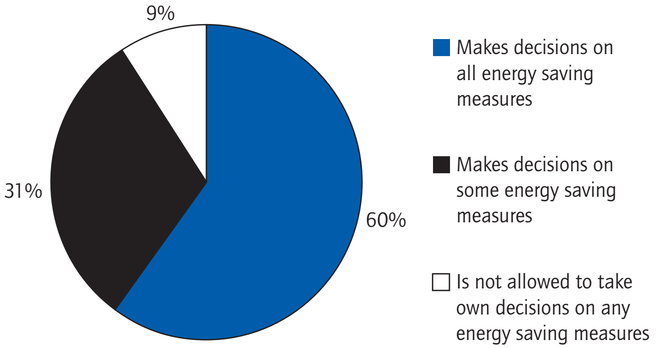
In the Netherlands, both tenants and owners of office space have the responsibility for paying their energy bills (Van den Ham, 1996). For premises that are occupied by more than one user, the owner of the building pays the gas bill for the building and passes the cost to the tenants. To simplify calculations, this study assumed that all offices pay their own energy bill in the end. Therefore, only Cases 1 and 2 are applicable (see Table 14).

As shown in Figure 15, in almost 60% of Dutch commercial offices, the end-user can make his/her own decisions concerning all energy saving measures. In 31% of the cases, end-users are allowed to decide some, but not all, of the energy saving measures to be taken. In 9% of the offices, the end-user is not allowed to make any decisions at all regarding energy saving measures (SenterNovem, 2004).

In the last two groups (representing about 40% of all commercial offices) the landlord of the building, in most cases (>65%), decides the energy saving measures to be taken. In 20% of the cases, the headquarters office or the executive board is responsible (SenterNovem, 2004).

FIGURE 15

Investment decisions on energy-saving measures in Dutch offices



Source: SenterNovem, 2004.

Table 14 summarises the results using this information.

TABLE 14

Principal-Agent problems in commercial offices in the Netherlands

	End user can choose technology	End user cannot choose technology
End user pays the energy bill	Case 1: No problem – **60%** of all offices (26 million RSF) – Owned: **17.3** million RSF (66.7% of case 1) – Rented: **8.7** million RSF (33.3% of case 1) Using less than 60% of the energy	Case 2: Efficiency problem – **40%** of all offices (17.2 million RSF) – Rented: 17.2 million RSF (100% of case 2) – Within this group **22.5%** is not allowed to choose any energy efficiency measures, **77.5%** is allowed to choose *some* Using over 40% of the energy
End user does not pay the energy bill	Case 3: Usage and efficiency problem This situation rarely occurs **~0%**	Case 4: Usage problem This situation rarely occurs **~0%**

After quantifying the office space represented by each case in the Principal-Agent matrix, this study calculated the corresponding energy use. Although some studies demonstrate differences in energy use in rented and purchased offices, the available data does not support higher energy use in rental offices.

Van den Ham (1996) recognised the split incentive in rented offices. This study addresses the common situation where tenants pay the energy bill and owners invest in energy saving measures. This situation is hindering investments in energy efficiency that require building adaptations or the installation of climate controls (Van den Ham, 1996) .

This study calculated the energy used by this group of end users assuming that the energy use per square metre is equal for purchased and rented office space. An efficiency problem can occur in 40% of offices (Case 2) and average energy use is 1435 MJ/m^2. The total energy use affected by PA problems is 24.5 PJ of primary energy. It is expected that energy use affected by PA problems in the rental sector should be higher than 24.5 PJ.

It is actually possible for tenants to influence part of the energy use by changing their behaviour. For example, they can lower the inside temperature and limit their use of lighting and other electrical appliances.

Analysis and implications

This study estimates that 24.5 PJ per year (40% of total energy use in the service sector) is affected by PA problems (Ecofys, 2007). An ideal calculation would include the difference between the energy use in rental offices and purchased office of the same size. However, this data was not available for this study. It would have been useful to know if owners of purchased offices indeed implement more energy efficiency measures than owners who rent their offices and do not feel the incentive to invest in energy saving measures.

The use of the EPC has resulted in reduced energy use in new office buildings, comprised mainly of a reduction in natural gas use (electricity use remains more or less the same). If the EPN had not been implemented, natural gas consumption for space heating and hot water in the services and commercial sector would have been 22% higher. Furthermore, if the EPC had not been introduced, energy use in the commercial sector would have been 1.5-5 PJ higher (Joosen, 2007). A study of SenterNovem (2004) also concludes that a downward adjustment of the EPC results in lower energy use in newly built offices, albeit with large variations for individual cases.

Conclusion and recommendations

Research shows that the energy use affected by PA problems is more than 24.5 PJ per year, which is over 40% of total energy use in commercial offices. In this case, the owner of the office space is shielded from price signals and cannot respond to higher energy bills, simply because he does not pay them. However, first hand statistical data could not be found. Further research should include a calculation of energy savings that could be achieved when PA problems is removed.

Although policies have been implemented to overcome the PA problems, there have not been significant results to date. Although the EPN has reduced overall average energy consumption, there is no evidence that the policy has altered the market over the long-term. SenterNovem concludes that a change in the policy would likely cause a return to the pre-policy situation. The Netherlands has recently changed approaches and seeks more long-term changes using financial incentives, among other things. However, to date, there are no specific policies addressing split incentives. The energy saving potential estimate remains at 24.5 PJ per year.

This case study underlines the importance of applying a balanced mix of policies rather than single instruments to overcome the PA problems. This idea will be further discussed in the last section.

PRINCIPAL-AGENT PROBLEMS IN COMMERCIAL OFFICE SPACE LEASING IN NORWAY

This case study quantifies Principal-Agent problems in commercial offices in Norway.

Energy use in the commercial office sector in Norway and energy efficiency policies

Energy use in commercial offices in Norway

Figure 16 shows the energy consumption for different end-uses in Norway by fuel source. Power intensive industries and households consume the most energy in Norway, using 30% of the total energy each, while other public and private sector customers consume 40%.

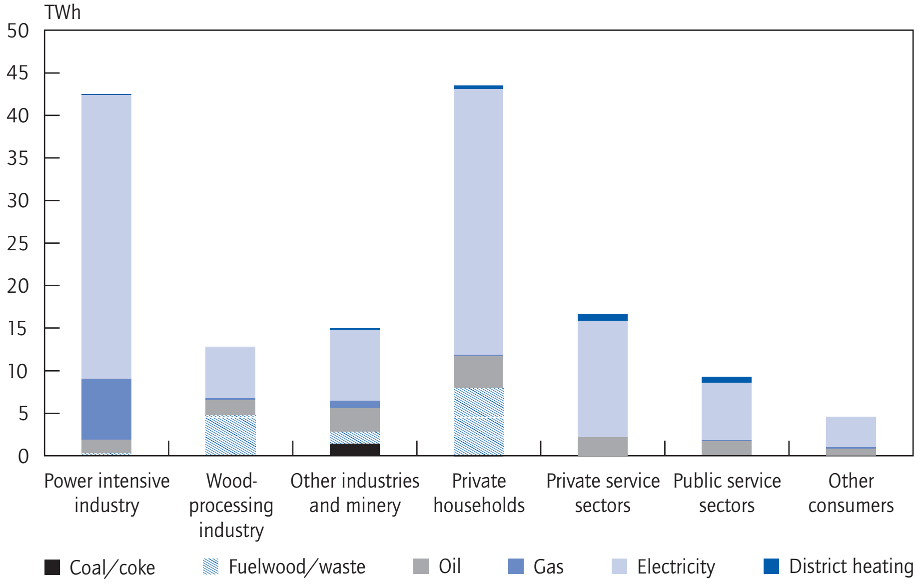
Heating, ventilation, lighting, office equipment and, increasingly, cooling, are the primary uses of energy in office buildings in Norway. Heating comprises more than 50% of commercial building energy consumption, 2/3 of which is electric (Ministry of Petroleum and Energy, 2005). In some cases, a dual-fuel unit that uses oil or electricity, depending on which fuel is less expensive, provides heating. District heating is also common in some of the largest Norwegian cities. However, this study assumes that electricity is the dominant fuel for heating Norwegian offices, both owner-occupied and leased.

Building energy use is high despite rather strict building codes. According to the building code, energy use should be less than 180 kWh/m^2 per year. In Enova's database, the average is approximately 240 kWh/m^2, and for the newest buildings, the average is approximately 290 kWh/m^2.

Electricity is the primary fuel in Norway. In 2004, electricity consumption was 392.4 PJ, or 65% of total stationary energy consumption of 604.8 PJ (Ministry of Petroleum and Energy, 2005). Traditionally, electricity has been relatively inexpensive because of the predominance of hydro-power generation. As a result, there is a widespread electricity transmission network with ample capacity, but hardly any infrastructure for gas distribution or district heating.

FIGURE 16

Stationary energy consumption in 2003 by energy carrier and type of consumer



Source: Statistics Norway, 2005.

Oil products and wood are the second most dominant energy sources in Norway. In 2004, the stationary consumption of oil was 82.8 PJ, gas was 23 PJ, and bio energy was 50.4 PJ, including 7.2 PJ from district heating.

There are only a few end-users of natural gas in Norway. They are located close to the areas where the gas is transported ashore from the North Sea. Currently, there are some on-going projects for building gas distribution systems to larger groups of end-users, particularly in the areas around Haugesund and Stavanger. In 2004, pipeline distribution of natural gas was 7.9 PJ. Natural gas delivered as CNG and LNG was 0.028 PJ and 1.7 PJ, respectively (Statistics Norway, 2005).

Energy efficiency policies

Norway has been a pioneer in liberalising and promoting its electricity market. Through the partial privatisation of Statoil, they have also made important progress in improving efficiency in the oil and gas sector.

However, awareness of energy efficiency issues among Norwegians is low due to the presence of cheap and abundant hydro electricity. Recently, growing concerns for the environment have pushed the government towards improved energy efficiency measures. Enova – the State owned enterprise to control energy-efficient policies – is working to reduce energy use by 43.2 PJ per year by the end of 2010 through a combination of measures. These include limiting energy use considerably beyond current levels, increasing the annual use of central heating from new renewable energy sources, heat pumps and waste heat by 14.4 PJ per year by the year 2010, and increasing wind power production capacity to 10.8 PJ per year by the year 2010.

In the commercial buildings sector, Enova's goal is to reduce energy use (primarily electricity use) in commercial buildings by 100 GWh per year by 2010 in buildings larger than 20 000 m^2 and by approximately 70 GWh per year in commercial buildings smaller than 20 000 m^2.

In 2002-03, the country faced a very cold and dry winter and a precipitation shortage. Access to electricity was difficult. The government instituted an emergency subsidy scheme which targeted specific energy appliances such as heat pumps, pellets ovens, and control systems. The subsidy was to cover a maximum of 20% of the investment costs, and was administered by Enova. Overall the programme's costs were EUR 10 m. In the residential sector, Enova ran EUR 10 m emergency programme in 2002-03 to reduce energy demand in response to the precipitation shortage. The programme offered direct financial support for heat pumps, pellet heating systems and control systems.

The programme was later transformed into a direct financial support on energy efficiency improvement. Enova later increased support to EUR 27.5 m to cope with high demand. Participating households (47 159) saved an average of 5 770 kWh per year, corresponding to a 33% average reduction in electricity used for heating. Estimates show total savings of 129 GWh[17] for the participating households (Enova, 2007).

This demonstrates that in times of crisis and widespread consumer awareness, changes in behaviours and habits can be made, and energy consumption rapidly reduced.

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[17] Under 2002 climatic conditions.

The size of Principal-Agent problems

Data collection

Statistics that separate building use (for example, between office and retail use) are not yet available for Norway. The same is true for statistics on office occupancy (owner or lease-holder) and on the design and content of lease contracts. Thus it is necessary to rely on qualitative judgments based on conversations with market players, combined with some building and employment statistics from Statistics Norway and an Enova database (Enova, 2005).

A standard rental contract includes heating (and cooling) as an add-on to the rent. However, energy use is normally not metred individually. The energy costs are distributed among the leaseholders, typically based on the share of total area. The amount of rent does not depend heavily on energy costs or other payable expenses for the landlord – the market rent for most offices simply reflect the balance between supply and demand for office space. Energy costs are typically 10-20% in comparison with the rent itself.

The length of lease contracts is normally three years or more. Most contracts are signed when buildings have already been constructed, which implies that users have little influence on building design. The exception is when an investor builds a new office for a dedicated user, in which case the user may express certain concerns about future energy use in the building. But such cases do not represent a "true" lease contract. Thus for the purpose of this analysis, these types of buildings are considered to be owner occupied, not leased office space.

Description of the results

The Enova database contains some detailed information about energy-related issues for a number of Norwegian buildings. The database includes buildings that Enova has been involved with on various types of energy efficiency projects. It is not a substantial database – 200 records out of a total of 1 800 buildings, and some of these records are within the same building because there are several tenants in the same building. Those items that are not termed lease-contracts are considered as owner-occupied space. Some public entities are included in the dataset. From this database, and according to the assumptions[18] of this study, it appears that the energy use per square metre is 20% higher in leased buildings than in owner-occupied space (230 vs. 190 kWh/m^2).

When data was unavailable, this study made the following assumptions:

- The energy consumption in leased office space is 20% higher than in owner-occupied buildings.
- There is 53 million square metres of office and retail store space in Norway. The statistics do not reveal the split between offices and stores, but this study assumed 30% of the total space is retail, and thus there is 37 million square metres of office space.
- 20% of total office space is owner-occupied. Therefore there is approximately 30 million square metres of leased office space.

An alternative approach would be to consider employment statistics. The study estimates that there are approximately 2.3 million employees in Norway, and 0.6 million occupy an office. Based on data from Enova (2005) the average heated space per office employee is 37 square metres, which yields 22 million square metres total office space. Assuming 20% is owner-occupied, this study estimates leased office space to be 18 million square metres.

The 30 million estimate appears to be high. To check the estimates, this study used estimates from real estate professionals. According to real estate brokers in Oslo, there are 10 million square metres of office space in the Oslo area, which is roughly one third of the total office space in Norway. Using the range of these estimates, there are approximately 22-37 million square metres of total office space in Norway, with 18-30 million square metres of leased office space.

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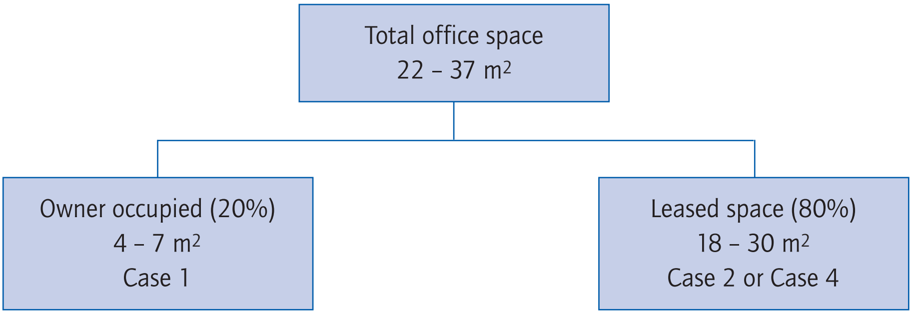
[18] First, the buildings entered into the Enova database are presumably receiving more energy efficiency assistance than other office buildings in Norway. Hence, there could be smaller difference between buildings in this database than in the full population. Second, energy consumption per square metre is not the only possible measure for energy efficiency. However, there is no other relevant proxy for building characteristics available in the dataset (such as people using or working in the building). Thus there is no alternative. Third, it is not satisfying that the sign of the conclusion depends on whether a few observations are included or not. But as the energy use in these few buildings appears extraordinary high in comparison with all other buildings in the database, it seems appropriate to exclude them (at least until the numbers can be verified). There is also reason to believe some of the relevant buildings are not entirely office buildings, but also include laboratories with a substantial amount of technical appliances.

FIGURE 17

Distribution of owner-occupied and leased commercial office space in Norway



This study further assumed the average energy consumption per square metre is 250 kWh/year. In the Enova database, the average is 240 kWh/m^2, but buildings in the Enova database may have a lower average energy consumption than the rest of the building population. This study assumed that the energy use in the owner occupied offices is 215 kWh/m^2 and 265 kWh/m^2 in leased office space. Consequently, estimated total energy use in Norwegian offices is between 19.8 and 34.2 PJ/year.

TABLE 15

Principal-Agent problems in commercial office space in Norway

Agent	End user can choose technology	End user cannot choose technology
End user pays the energy bill	Case 1: 3-5.4 PJ 10-20% of the energy use in the sector	Case 2 & Case 4: 18-28.8 PJ 80-90% of the energy use in the sector
End user does not pay the energy bill	Case 3: nil	

As mentioned above, total energy use tends to be 20% lower in owner-occupied offices compared to leased offices in the Enova database. Because this study assumes the buildings in this database tend to have higher energy efficiency than the national average, this difference translates to 50 kWh/m^2 higher energy use in leased office space. If the barrier was removed, this study estimates the potential savings would be 1.5 (0.9) TWh/year (50 kWh/m^2 and 30 (18) million square metres yields 1500 (900) million kWh) or approximately 15% of the total energy use in the sector.

Analysis and implications

Implications of the results

Results reveal the existence of PA problems in the commercial office sector, affecting approximately 80% of the energy use in the sector, or 28.8PJ/year. The approach used to reach this conclusion is rather conservative. Accordingly it tends to underestimate rather than overestimate the energy use affected by PA problems and the energy saving potential for removing PA problems.

These findings underline the impact that inexpensive and accessible energy sources can have on the energy use of a country, and the difficulties it fosters in altering the market. Although the Norwegian government has tried to implement different energy efficiency programmes, energy use has only decreased temporarily in times of crises (2002-2003). Policy packages to date have not been able to significantly alter the market.

Conclusions and recommendations

The hypothesis in this case study is that leased office space has higher energy consumption than owner-occupied commercial office space. Although it is based on limited evidence, the analysis supports the hypothesis. Energy use is approximately 50 kWh/m^2 higher in leased office space in Norway. Using a range between 18 and 30 million square metres of office space, the potential energy savings are estimated to be 3.24 to 5.4PJ/year, or 15% of the total energy use in the sector, if PA problems were removed.

Residential sector: case studies

PRINCIPAL-AGENT PROBLEMS IN THE RESIDENTIAL SECTOR

This chapter focuses on Principal-Agent problems in the residential sector in several end-uses in the United States and the Netherlands. The United States case studies investigate and quantify PA problems for refrigerators, water heaters, space heating, residential lighting, and set-top boxes. The Netherlands case study addresses and quantifies PA problems for space heating in rented houses. This overview chapter applies Agency Theory to the specific characteristics of energy efficiency in the residential sector.

Agency Theory and energy efficiency issues in the residential sector

Using the same dimensions of Agency Theory from Chapter 2, Agency Theory can be applied to energy efficiency markets. A summary is presented in Table 16.

Identifying the principal and the agent in residential energy efficiency markets

Figure 18 illustrates the transactions between principals and agents specific to the residential sector.[19]

In the residential market (except the set-top box market), the renter (principal) pays the landlord (agent) for the use of the apartment and any included furniture and appliances. In the US, the tenant does not specifically request that the landlord choose the appliances and any included appliances are

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[19] In the residential sector, the conceptualisation of principal and agent must be stretched beyond a strictly literal definition, as PA problems often exist between renters and landlords.

TABLE 16

Dimensions of Agency Theory applied to residential energy efficiency transactions

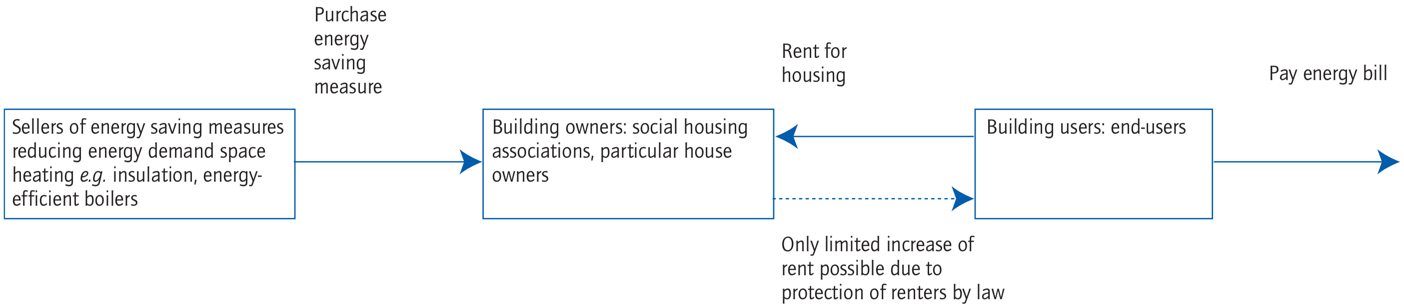
Dimension	Standard application of agency theory (owner-manager)	Residential energy efficiency context (landlord-tenant example, Case 2)
Unit of analysis	Relationship (and contract) between owner (principal) and manager (agent)	Relationship (and contract) between landlord (agent) and tenant (principal)
Problem domain	Relationships in which the principal and agent have different levels of information and partly differing goals	Relationships in which the principal and agent have different levels of information about energy efficiency and partly differing goals
Goal orientation of the actors	Goal conflict between principal and agent. Owner's goal is to maximise returns. Manager's goal may be to limit work levels required.	Goal conflict between principal and agent. Landlord's goal is to maximise returns/minimise capital costs. Tenant's goal is to limit energy costs
Key objective	Principal-agent relationships should reflect efficient organisation of information to maximise economic efficiency	The energy user *and* energy technology selector should both consider energy costs
Human assumptions	Self-interest Bounded rationality Individual autonomy	Self-interest Bounded rationality Individual autonomy
Organisational assumptions	Partial goal conflict Economic efficiency as the criterion Information asymmetry Agent delegated the task by passive owner principal	Partial goal conflict Energy efficiency as the criterion Information asymmetry Agent provides accommodation to tenant (principal)
Assumption about the source of problem	Contract inadequate	Contract inadequate in that is set up in a way that at least one party that is involved in energy-related decisions is insulated from the energy price
Implications of inefficient relationship/ contract	Adverse selection Moral hazard	Adverse selection Moral hazard Inefficient energy use

usually already in place. The "principal" can be considered as the whole set of possible renters. These principals would prefer to have efficient appliances that produce lower utility costs, but their agents, the landlords, are more concerned with initial costs since they do not incur the expense of running the appliances.

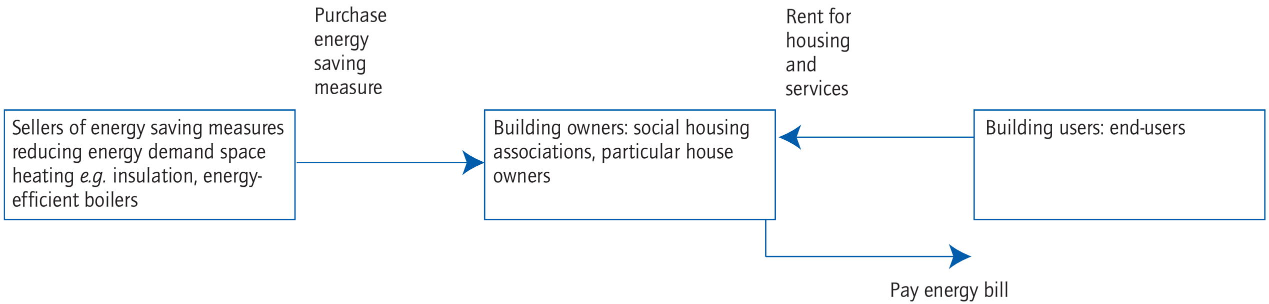
FIGURE 18

Principal and agents in residential energy efficiency transactions

Case 2 End-user does not choose technology, but pays the energy bill. Efficiency problem



Case 4 End-user does not choose technology and does not pay the energy bill. Usage problem

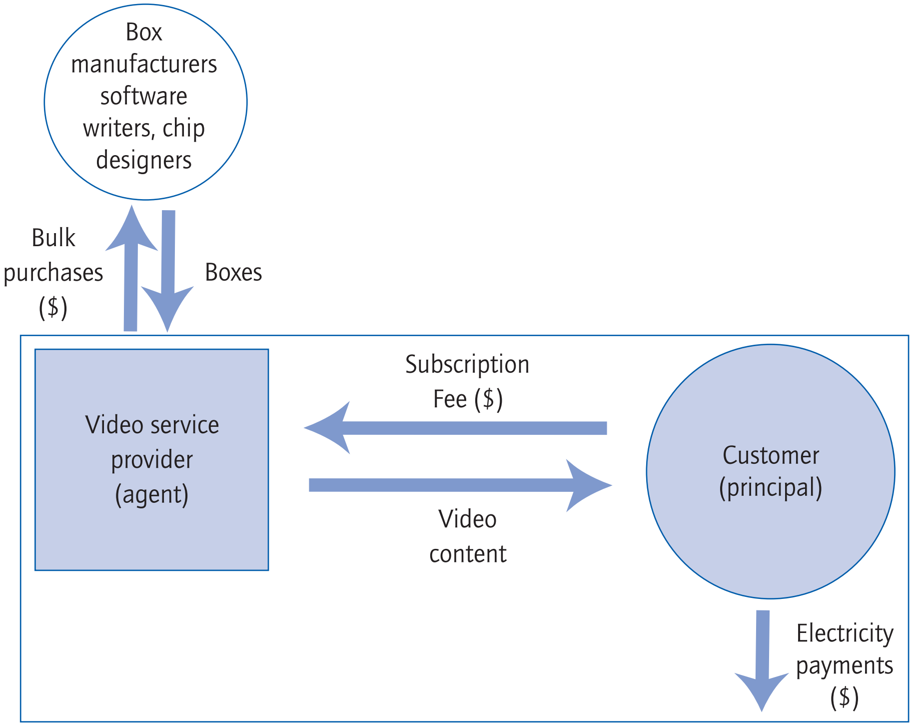


In the set-top box market, three groups are involved in transactions (see Figure 19): the consumer, the service provider, and the box manufacturer.

The consumer is the *principal* in the contract with the service provider. In return for a monthly subscription fee, the consumer receives video signals through a set-top box.

FIGURE 19

Transactions in the set-top box market



The service provider is the *agent* in the relationship with the consumer. The service provider creates or purchases information content and offers it to customers. The service provider purchases set-top boxes in bulk from manufacturers. In this relationship, the service provider is the principal and the manufacturer the agent. The service provider dictates the boxes' technical specifications while the manufacturer determines other specifications.

Identifying Principal-Agent problems in the residential sector

By searching for transactions where PA problems may be present and understanding who pays the energy bill and who makes decisions on energy saving measures, PA problems in the residential sector can be categorised into four cases.

TABLE 17

Principal-Agent problems from the end-user (tenant) perspective

	End user chooses technology	End user does not choose technology
End user pays the energy bill	Case 1: No problem	Case 2: Efficiency problem
End user does not pay the energy bill	Case 3: Usage and efficiency problem	Case 4: Usage problem

Case 1 generally includes residences that are occupant-owned, *e.g.*, single family residences and condominiums. These residents generally choose their own appliances, furnaces, air conditioners, and other energy-using equipment.[20]

This group of end-users has an incentive to take energy saving measures, because decreased energy use has a direct influence on the energy bill.

In *Case 2*, households are mostly composed of individually-billed rental households and new owner-occupied houses where the occupants did not select one or more energy-using appliances or features. Most occupants, whether owners or renters, pay their own utility bills.[21] An efficiency problem arises, because if the

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[20] In new homes, these items are often pre-installed and the residents cannot choose the items' energy efficiency until the originals are replaced. Case 2 generally applies to these households.

[21] A significant number of renters have some utilities included in their rent. This is less true of electricity than other fuels since most housing units are individually metred for electricity. These households fall into Case 3 and Case 4. Most of these households are rental units, covered by Case 4. The Case 3 units would consist of a small number of condominiums where the cost of one or more fuels is included in a condo fee.

person paying for energy is not the person choosing the technology, the technology buyer will generally choose among the cheapest, and often not the most energy-efficient, options.

In the Netherlands, since the end of 1995, the building standards for new houses include requirements about the energy performance of a house. These requirements are gradually upgraded over the course of time. In practice, this means that energy-efficient energy systems are automatically introduced in new homes.

In *Case 3*, the landlord, or housing associations, pays the energy bill, while the tenant makes investment decisions. In practice this situation will seldom occur.

In *Case 4*, the tenant neither pays the energy bill nor is allowed to take investment decisions on energy saving measures. Cost effective measures might be implemented, because the owner tries to optimise energy costs. On the other hand, the end-user of the energy will not have an incentive to reduce energy use because higher energy costs are not directly passed on to the end-user. Here, a usage problem arises.

The status of information on residential equipment performance is central to PA problems in residential energy efficiency markets. There can either be no information, which does not generally apply to the end-uses examined in the residential case studies. Or, the manufacturers may have determined the efficiency of their products, but are not required to provide the information on efficiency labels. This is not the case in the US for refrigerators,[22] gas and electric water heaters, and space heaters, as energy labels are mandatory. In other cases, information is available, but is asymmetric. The landlord has the opportunity to inspect efficiency labels before purchasing equipment, but can then remove the labels before installing the devices. An unscrupulous landlord could claim that the appliances are particularly efficient, even when they are not. Alternatively, both the principal and the agent have adequate information and education to know whether the equipment is the best choice.

In the residential sector, PA problems have significant impacts on investments in energy saving measures in all the case studies. However, there are several caveats. In Case 1 and Case 3, when categorising the occupants of a household as being able to choose their own technologies, this line can be unclear. For example,

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[22] Including refrigerator-freezers, chest freezers and upright freezers.

water heaters are frequently replaced following a catastrophic failure. Homeowners generally call one or two plumbers and take whatever model that plumber happens to carry in stock. In a sense, a PA problem exists because the plumber could install a more efficient model to reduce the homeowner's long-term costs.[23]

It is also important to keep in mind that the number of households falling into each case depends on the end-use. For example, an apartment dweller may not be able to choose her own water heater, but is able to choose her own television. Assuming she pays for her own energy usage, she would fall into Case 1 for televisions but Case 2 for water heaters. In addition, the matrix describes a given set of households at one point in time. Housing units may move from one category to another over time. This often happens when a pre-installed device must be replaced. The homeowner may have had no choice when first buying the house but can choose the replacement unit when the original device fails. A housing unit can also move from one category to another if its tenancy status changes. This happens when a homeowner buys a new house and keeps possession of the first one to use as a rental property or when an apartment building is converted to condos.

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[23] However, a well-informed homeowner (or a patient one who doesn't mind going without hot water for a couple of days) can avoid being at the mercy of the plumber's water heater selection. A very conscientious homeowner may know that a water heater is nearing the end of its expected lifetime and do some prior research to be prepared for the failure of his water heater. Thus, for purposes of this study, replacements of water heaters by occupant-owners are classified as a Case 2 PA problem for some households and as a Case 1 for others, based on an assumed rate of emergency replacements.

REFRIGERATOR, WATER HEATER, SPACE HEATING AND RESIDENTIAL LIGHTING ENERGY USE AFFECTED BY THE PRINCIPAL–AGENT MARKET FAILURE

This study[24] investigates the magnitude of Principal-Agent problems in four common energy end-use appliances in the US residential sector:[25] space heating, water heating, refrigeration and lighting. These end-users were selected because they consume a significant proportion of residential energy. In 2001, these four end uses accounted for nearly 73% of US residential energy consumption.

Energy use in the US residential sector and energy efficiency policies

Energy use in the residential sector in the US

The Census Bureau's American Housing Survey 2003 (AHS, 2003) (US Census Bureau, 2005) lists 105.8 million year-round occupied residences in 2003. Of these there were 74 million single-family residences (SFRs), 25 million multifamily residences (MFRs), and 6.9 million mobile homes. The housing type tends to be a strong determinant of energy consumption. In 2001, SFRs and mobile homes used almost twice as much energy per household as MFRs (The Department of Energy, 2004). About 68% of housing units in the US are occupant-owned. In general, occupant-owned units tend to be SFRs or mobile homes (about 5% of occupant-owned MFRs were condos), while 64% of all rental units are MFRs.

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[24] Based on work by Murtishaw and Sathaye (2007), "Quantifying the Effect of the Principal-Agent problem on US Residential Energy Use", LBNL report.

[25] Note that energy inefficiencies arising from barriers to energy efficiency that are primarily related to lack of information, or the inability to process it, are not included in this study. Generally, information barriers involve an occupant able to choose devices he or she will use without access to, or interest in, performance information. In either case, the occupant fails to purchase a comparable, more energy-efficient model.

According to the Residential Energy Consumption Survey 2001 (RECS, 2001) US households used 9.84 exajoules (EJ) of delivered energy (The Department of Energy, 2004).[26] The distribution of delivered energy by end-use is shown in Table 18. Space heating is by far the largest single end-use of site energy, accounting for nearly half of all energy consumed in 2001.

TABLE 18

Site energy consumed by end-use in quadrillion Btu and exajoules, 2001

End-use	QBtu	Shares of final energy, QBtu	EJ
Space heating	4.62	46.9%	4.47
Water heating	1.68	17.1%	1.65
Refrigerators	0.53	5.4%	0.56
Lighting	0.34	3.5%	0.36
Air conditioning	0.62	6.3%	0.65
Appliances & misc.	2.06	20.9%	2.17
Total	**9.86**	**100%**	**9.84**

Source: The Department of Energy, 2004; and Energy Information Administration, 2005.

Energy efficiency policies

Standards, information campaigns, financial incentives for efficient devices and other policies all influence the extent to which PA problems determine actual energy use in the US residential sector. Regulations and non-regulatory (such as voluntary agreements with manufacturers) policies can influence the actions of principals and agents, enabling and encouraging both to choose energy-efficient devices for residential use.

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[26] One quadrillion (10^{15}) Btu equals 1.055 exajoules (10^{18} joules). Because energy figures are given in gross calorific values (GCV) in the US and net calorific values (NCV) in most other countries, a correction must be made to the reported energy data to make them comparable to the système international units used elsewhere. The GCV to NCV factors are 1 for electricity, 0.95 for liquid fuels, and 0.9 for natural gas. Coincidentally, with the final fuel mix reported in RECS 2001, the conversions balanced each other out to within 0.1%.

Minimum Energy Performance Standards (MEPS) were established for many household appliances in 1987. MEPS remove the market's least-efficient models by requiring manufacturer compliance with regularly-improved energy standards. From 1987 to date, US appliance standards have been implemented for 40 product types. Eighteen updates have been implemented on 14 product types; some product types have had more than one update since the original standard (including clothes washers, refrigerators, freezers and fluorescent lamp ballasts). MEPS for refrigerators, first introduced in 1990, were revised the first time in 1993; the latest standard became effective on July 1, 2001. The Energy Policy Act of 1992 established MEPS for water heaters,[27] most recently revised to be effective in January 2004.[28] MEPS for space heaters became effective in 1990. The Energy Policy Act of 2005 mandated additional or modified standards for many appliances, the first of which will come on line in 2007.[29]

Ever-tightening MEPS reduce the practical effects of PA problems over time. However, MEPS do not completely eliminate PA problems because MEPS remove the least energy-efficient appliances from the market. There is still no guarantee that agents acting in their principals' best interests would select the most energy-efficient model. These models are identified in the US by the ENERGY STAR label.

Voluntary information-related policies have also been used extensively in the USA. For example, the voluntary ENERGY STAR labelling program was launched in 1992. It is used to identify energy-efficient computers, monitors and printers and now includes a variety of appliances, equipment, homes and windows. In 1996, certain refrigerators[30] first qualified for the ENERGY STAR label. Regularly updated along with MEPS, ENERGY STAR most recently required labelled models to use 10% less energy than the July 1, 2001 MEPS level for models of similar size and configuration.[31] In February 2007, the US Department of Energy announced a development schedule for expansion of ENERGY STAR to include water heaters.

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[27] Including gas, electric, and oil water heaters, heat pumps.

[28] MEPS for water heaters do not come up for revision again until 2010.

[29] See http://www.eere.energy.gov/buildings/appliance_standards/ for more detail on timing of MEPs in the USA.

[30] To qualify for the ENERGY STAR label, refrigerators must be automatic defrost. Top-freezer models must be at least 12.5 ft^3 in total volume. Side-by-side and bottom-freezer models must be at least 18.5 cubic feet in total volume.

[31] ENERGY STAR-labelled oil and gas furnaces, which have annual fuel utilization efficiency (AFUE) ratings of 83% and 90%, are approximately 15% more efficient than standard models. Qualifying electric air-source heat pumps are about 20% more efficient than standard new models, based on relative heating seasonal performance factors and seasonal energy efficiency ratings. ENERGY STAR geothermal heat pumps use 40%-60% less energy than standard heat pumps. To qualify for the ENERGY STAR label, boilers must have an AFUE rating exceeding 85%, 6% more efficient than the minimum federal standard for boilers. Water heating is the only major residential energy end use that ENERGY STAR does not address.

The voluntary ENERGY STAR program complements the US mandatory EnergyGuide label that has covered many appliances, including water heaters, space heaters and refrigerators, since 1980.[32]

Government-sponsored media campaigns further inform consumers of energy-efficient products and incentives for efficiency investments. Some campaigns encourage occupants to audit their structures for efficiency and heat loss – the US Department of Energy even offers tips to residents on how best to judge insulation quality by drilling small holes in principle walls. Manufacturers of efficient devices occasionally partner with local governments to promote home auditing and inform consumers of efficient products.

Those information campaigns all help to address one of the main contributors to PA problems in the US residential sector: lack of information. However, despite these policies, this study still found evidence of PA problems in this sector.

A range of financial incentives encourages appliance buyers to choose energy-efficient devices. For example, governments sponsor rebate programs to reduce the initial cost of efficient equipment. At the federal level, the 2005 Energy Policy Act provides tax credits to consumers, home builders and appliance manufacturers. Consumers qualify for improvements in insulation, windows and high-efficiency heating and cooling equipment between 2006-7 (the effect of such incentives does not appear in the 2003 scenarios described in this study). Consumers buying gas, oil and propane water heaters at least 33% more efficient than the current federal standard and electric heat pump water heaters are at least twice as efficient as the current federal standard qualify for tax credits.[33]

Builders, the agents for buyers of new houses with pre-installed water heaters, refrigerators and space heating systems, qualify for building energy-efficient homes and producing manufactured homes. Within a three-year window, builders of homes that save 50% of heating and cooling energy relative to the 2004 International Energy Conservation Code (IECC) may take a tax credit. Building envelope improvements must provide at least one-fifth of the energy savings. Builders of manufactured homes meeting EPA ENERGY STAR guidelines or

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32. In 1980, the Federal Trade Commission's Appliance Labelling Rule became effective, requiring all new appliances to bear EnergyGuide labels. The FTC remains responsible for the program's label design and compliance regulation.

33. Home improvements can earn consumers a maximum of USD 500 in tax credits; investment in efficient water heaters qualifies for a credit of USD 300. Installation of solar water heating will be credited at 30% of the cost, up to USD 2 000.

achieving 30% energy savings from heating and cooling relative to the 2004 IECC also qualify for the tax credit. Manufacturers of refrigerators more efficient than the 2001 federal energy conservation standards are eligible for tax credits.

Comprehensive evaluations of the Energy Policy Act's tax incentives for efficient residential energy end use have yet to be published. However, the ACEEE released a study in August 2006 naming four prime impediments to the incentives' success: the price premium for value-added appliances, the market's paucity of qualifying models, the skewed geographic concentration of qualifying models, and manufacturer resistance to ever-improving efficiency standards. Elsewhere, the Energy Policy Act's success remains to be gauged.

The size of Principal-Agent problems for US refrigerators

Data collection

Refrigerators are different from many other energy-consuming appliances. For a given refrigerator, energy consumption is not responsive to energy cost because household occupants do not use the refrigerator "more" as a consequence of not paying energy costs. As a result, the classification simplifies into determining those cases where there is an efficiency problem. In Case 4, there is no PA problem because it is in landlords' interest to choose an efficient refrigerator given that they are paying the cost of electricity.

Figure 20 illustrates how the factors influencing whether a PA problem exists for a given household determine which case the household is allocated to. Five levels of factors affect the final designation of the households into their respective cases: 1) whether the household is a SFR or MFR; 2) whether it is occupant-owned or rented; 3) if occupant-owned, whether it was constructed in the last fifteen years (the approximate average lifespan of a refrigerator);[34] 4) if rented, whether the landlord provides the refrigerator or not; and 5) whether electricity is included in rent or other fees. These factors produce 12 types of households for the purposes of this analysis, which are represented by the end points in Figure 20.

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[34] This matters since many newly completed residences have the refrigerator pre-installed. Even though the house or condo is built for occupant ownership, the purchaser may not be able to choose the refrigerator model. However, once the original refrigerator fails, the owner chooses the replacement refrigerator.

Table 19 groups the households from Figure 20 by case and shows both the number of households falling into each case (with the percentage of the total in brackets) as well as the amount of site energy consumed annually in petajoules (PJ), by the refrigerators in these households. The percentages differ because there is a higher proportion of SFRs in Case 1, and SFRs tend to have both larger refrigerators and a higher number of second refrigerators.

TABLE 19

Principal-Agent classification for refrigerator users by number and share of households and site energy for refrigeration end use[35]

	End user can choose technology	End user cannot choose technology
End user makes direct energy payment	Case 1: 70.8 million households **[67%]** 403 PJ **[72%]** Occupant-owned residences: Most newer ones Those older than 15 years[a] Rental units: Those with no refrigerator included	Case 2: 30.4 million households **[29%]** 141 PJ **[25%]** Occupant-owned residences: Some newer ones Rental units: Most of these units
End user does not make direct energy payment	Case 3: 0.3 million households **[0%]** 0.95 PJ **[0%]** Condominiums: Small number Rental units: Small number	Case 4: 4.4 million households **[4%]** 15.4 PJ, **[3%]** Condominiums: Small number Rental units: Significant number[b]

[a] assumes original refrigerator has been replaced by owner.

[b] for refrigerators, no efficiency problem exists assuming same agent (*e.g.*, landlord) chooses technology and pays for energy. This may not be true in some newer buildings where electricity is included in rent if the developer selected refrigerators instead of the landlord.

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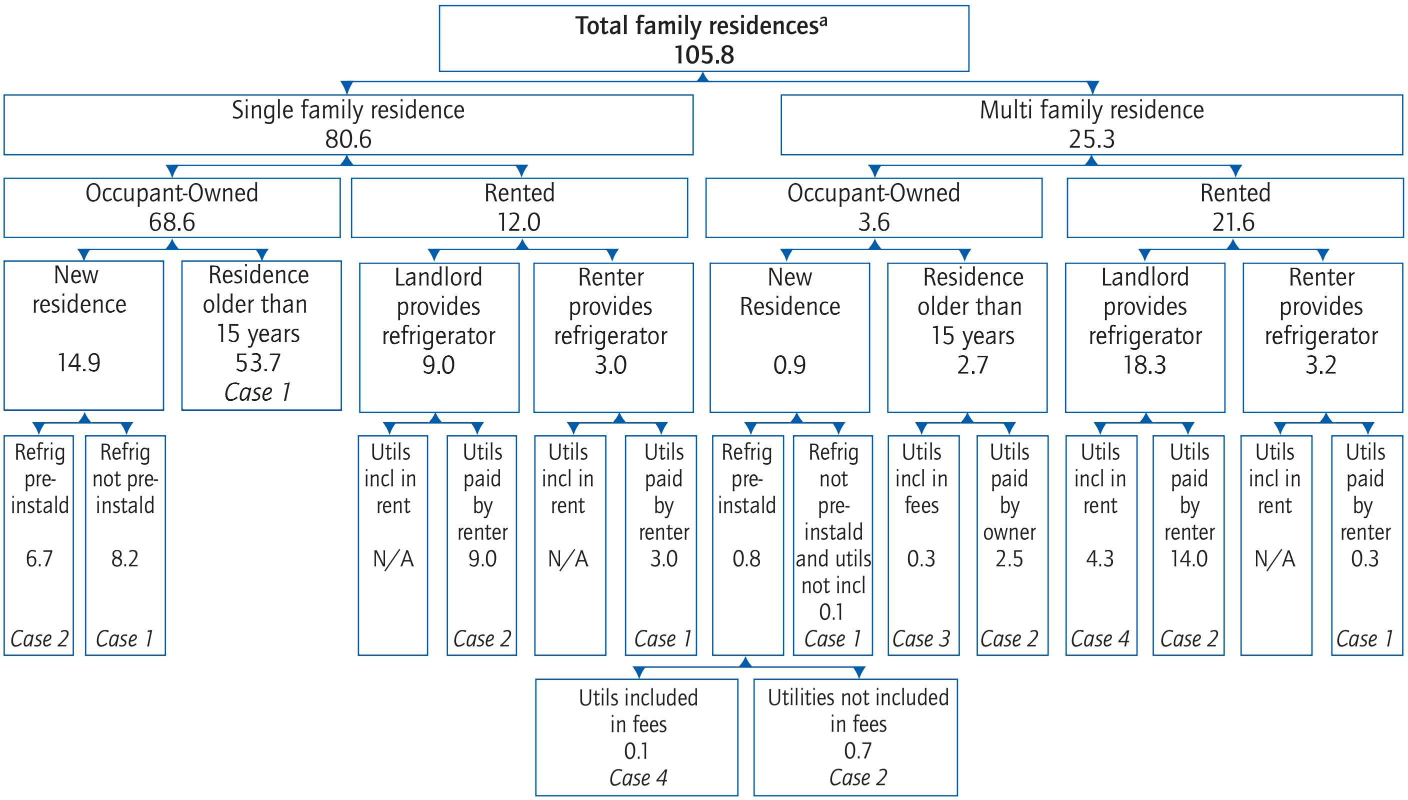
35. Data used for these calculations came from four different sources. Data on number of refrigerators in the stock and energy consumption for refrigeration are from RECS (The Department of Energy, 2004). Data on number of housing units by unit type, year of completion, and ownership status are from the AHS 2003. Statistics on whether utilities are included in rent are also taken from AHS. Figures on the number of single family and multi-family housing units completed in 2003 with refrigerators pre-installed were provided by the National Association of Home Builders (Cartwright, 2005). Data on refrigerator shipments and average shipment-weighted energy consumption were drawn from the Association of Home Appliance Manufacturers' 2003 fact book (Association of Home Appliance Manufacturers, 2003).

FIGURE 20

Refrigerator decision tree for allocating households to four Principal–Agent cases (millions of households)



[a] Numbers in parent categories will not always equal the sum of subordinate categories due to rounding.

Case 1

Although refrigerators are pre-installed in many new occupant-owned and rented units, when a refrigerator in an occupant-owned unit must be replaced, this study assumes that the occupant always has control over the model selected. Therefore an occupant-owned household with pre-installed appliances is affected by a PA problem when the unit is first purchased but ceases to be affected when the appliances are replaced. This necessitates splitting occupant-owned units into newer and older households on the basis of the average lifespan of the appliance in question. Since the average refrigerator lifetime is 15 years, occupant-owned units are split into two groups on this basis (see Annex for details of calculations).

Case 2

Case 2 units consist of the 45% of new occupant-owned SFR units (6.7 million) where the refrigerator is pre-installed and the 75% of rental SFRs with the refrigerator included (9 million). In addition, there are the 85% of new occupant-owned MFR units with a pre-installed refrigerator and occupant-paid electricity (0.7 million). Subtracting the units where the electricity is included in rent or other fees from the 85% of all rental MFR units that include a refrigerator leaves 14 million households. This produces a total of 30.4 million households in Case 2.

Case 3

For Case 3, this study assumed that in no case where the utilities are included in a rental unit does the tenant supply its own major appliances. However, according to AHS, in roughly 0.33 million occupant-owned MFRs electricity is included in a flat or combined fee. These were split into old and new units using the share of old units in the condominium stock (77%). This accounts for the 0.25 million households in case 3. It was also assumed that AHS figures on SFRs with electricity included in rent or other fees (most of which are occupant -owned) are simply misreports.[36]

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[36] The information on whether utilities are included in rent or other fees is given in response to a survey question that asks respondents to provide their average monthly costs for each fuel. When multiple utilities are included on one bill, respondents who rely on payment records instead of detailed bills cannot provide accurate estimates of the monthly cost of each fuel. These respondents often indicate that energy costs are included in rent when they use payment records to estimate energy costs.

Case 4

Case 4 consists of the 0.08 million newer condominium units where both the electricity and refrigerators are included (*i.e.*, the remainder from Case 3) as well as the 4.3 million rental MFR units that, according to AHS, have electricity included in rent or other fees. This study assumes in all cases where utilities are included for rental MFRs, the refrigerator is also included. Together with the households in case 1, this results in 75.1 million residences without a PA problem.

Description of the results

Besides the lack of variability in users' demand for refrigerator services, refrigerators are an unusual appliance in that many households have more than one unit. According to RECS, over 18 million households have two or more refrigerators. To incorporate the secondary refrigerators into the stock of refrigerators affected by PA problems, the secondary refrigerators were allocated into rental SFRs and MFRs using the ratio of rental units in each class in the total stock.[37] Allocating a proportional share of secondary refrigerators to rental units results in another 2.9 million refrigerators. The total stock of affected refrigerators is 33.6 million or about 27% of the stock of refrigerators reported in RECS.

The estimated energy use affected by the PA problem in refrigerators in the US residential sector is approximately 141 PJ.[38] This amounts to 25% of energy consumed for refrigeration and 1.4% of total 2001 residential site energy consumption. This is equivalent to 415.7 PJ[39] of primary energy affected or 2.2% of total 2001 residential primary energy.

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[37] Also, it was assumed that in no case in an occupant-owned unit is the secondary refrigerator not chosen by the occupant. It was also assumed that no secondary refrigerators fall into Case 4. In other words, in rental units with landlord-paid utilities, landlords will not substantially add to their electric bills by leaving a second refrigerator in the unit.

[38] In order to calculate the energy consumed by the affected refrigerators, the stock was subtotaled by units in SFRs and MFRs since the average household energy consumption differs substantially between the housing types. RECS disaggregates households by four types (SFRs, MFRs with 2 to 4 units, MFRs with 5 or more units, and mobile homes), but mobile homes were aggregated with SFRs and all MFRs were added together and weighted average per household energy consumption figures were used to simplify the analysis. There are 15.1 million refrigerators in MFRs and 18.5 million in SFRs. Each of these figures were multiplied by the respective average refrigerator consumption per household to estimate affected energy use of 141.4 PJ.

[39] To convert the delivered energy to primary energy data on total inputs to electricity generation was used (assuming 33% conversion efficiency for nuclear) and total consumption of electricity from the EIA's Electric Power Annual 2003 (Energy Information Administration 2004a) . From this a primary energy coefficient was derived for electricity consumed of 2.94, which incorporates transmission and distribution losses.

In addition to calculating total energy affected by PA problems, this study estimated the possible savings from one year of refrigerator sales if all refrigerators sold that year were not affected by these split incentives. Annual savings from a single year's worth of sales would be 78 million kWh/year. Ideally, it would have been useful to have data on the differences between the efficiencies of similarly sized refrigerators purchased by buyers who will pay the energy costs versus refrigerators bought by others on behalf of the utility payers. Unfortunately, RECS 2001 does not provide this data. Thus, this study had to make several assumptions (see Annex).

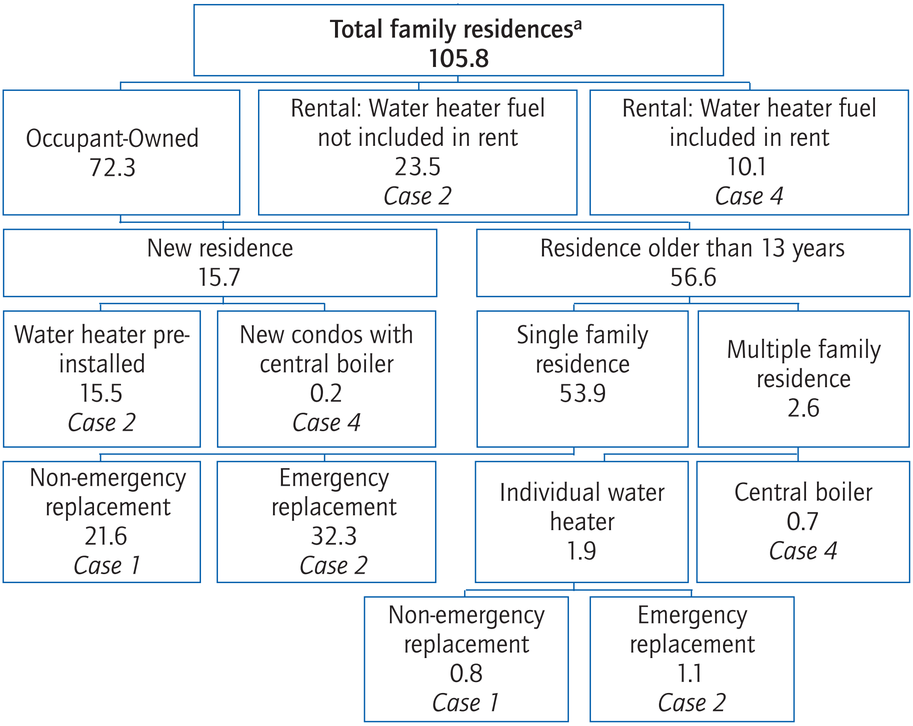
The size of Principal-Agent problems for water heaters

Data collection

This study used data for the water heaters calculations from AHS 2003 and RECS 2001. The conceptual framework for determining the extent of PA problems is the same as that shown in Table 19. Since end-users do have some control over hot water use, the exception to PA problems noted for refrigerators in Case 4 does not apply. Figure 21 demonstrates how the framework is applied for residential water heating. The classification is somewhat simpler than for refrigerators because renters and new home buyers rarely select their own water heaters. This study found no data on the incidence of water heater choice in new homes. Thus, for purposes of allocating households into the various cases, this study assumed that new home buyers never select their own water heaters. Occupant-owners who replace their own water heaters often do so only in an emergency. In the absence of any published data on this phenomenon, this study assumed this occurs 60% of the time. This leaves an estimated 40% of older occupant-owned units where owners actively choose their own replacement water heaters, as the only category of end-users not affected by a PA problem. The exceptions are older condo units with central boilers to supply hot water (Case 4) and older condo units with individual water heaters whose water heating fuel is included in condo fees (Case 3). Table 20 aggregates the households in Figure 21 by case (the Annex provides details of the calculations behind these estimates).

FIGURE 21

Water heater decision tree for allocating households to four Principal–Agent cases (millions of households)



[a] Numbers in parent categories will not always equal the sum of subordinate categories due to rounding.

Description of the results

This study estimates that PA problems affect approximately 1 254 PJ of delivered energy (see Annex for more details). Estimating total primary energy affected required additional steps to produce a separate estimate on the share of electricity in the total energy affected by PA problems. Using the approach outlined in the Annex to account for energy mix, calculations reveal that approximately 1 918 PJ of primary energy or 11.3% of total residential primary energy is affected by PA problems in the US residential water heating sector.

TABLE 20

Principal-Agent classification for water heaters by number and share of households and site energy

	End-user can choose technology	End-user cannot choose technology
End-user makes direct energy payment	Case 1: 22.4 million [21%] [23%], 378 PJ 40% of occupant-owned SFRs older than 13 years[a] 40% of occupant-owned MFRs, older than 13 years, w/ individual water heaters, utilities not included	Case 2: 72.5 million [68%] [68%], 1,102 PJ Most rental units Newer occupant-owned units 60% of occupant-owned units, older than 13 years, with individual water heaters
End-user makes indirect energy payment	Case 3: Negligible Possibly a small number of condos older than 13 years w/ individual water heaters	Case 4: 11.0 million [10%] [9%], 152 PJ Significant number of rental units Condos with central boilers Newer condos with utilities included

[a] Assumes original water heater has been replaced by owner.

Using an approach similar to that used to estimate potential refrigerator savings, this study estimated annual savings from one year's worth of water heater sales (see Annex). Together, PA problems affected an estimated 4.0 million gas water heaters and 3.4 million electric water heaters shipped in 2003 (more than 77% of all water heaters shipped that year). With RECS data on average water heating consumption by housing unit type and fuel, 80.2 PJ of natural gas and 31.7 PJ of electricity (173 PJ of total primary energy) will be consumed by these water heaters each year. According to estimates, without PA problems, annual savings from 2003 sales of water heaters would amount to 9.6 PJ of site energy and 12.6 PJ of primary energy. As an additional estimate of potential savings, this study estimated that annual savings from individual billing of the entire stock of units included in Case 4 could be as high as 15.8 to 31.7 PJ, assuming a 10% to 20% reduction in usage due to billing.[40]

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40. This range was selected on the basis of a study on the impact of submetering on water use in MFRs that found an average 15% reduction compared to master-metered apartments (Mayer *et al.,* 2004).

The size of Principal–Agent problems for space heating

Data collection

The factors determining the presence of PA problems for space heating are nearly identical to water heating.[41] As with water heating, there are two types of PA problems: disincentives to purchase energy-efficient equipment and disincentives to use the equipment efficiently. The former occurs when users are not able to choose their own equipment and the latter when users do not incur costs proportional the amount of energy they consume.

As with water heating, the most important characteristics for allocating housing units include their tenancy status, age, and inclusion of energy costs into flat or common fees. Figure 21, the decision tree used to disaggregate the housing units by the PA typology for water heating, applies to space heating as well, although the number of units in each case differs as described below.[42] In rental households, tenants will almost never have any influence on the choice of furnaces and other major structural items (such as windows and ceiling or wall insulation) that affect space heating. Virtually all rental households are affected by PA problems. When tenants pay a proportional energy cost they fall into Case 2. When energy costs are included in fees or are billed in common, units fall into Case 4.

Residents in occupant-owned units theoretically do have control over equipment choices, but as with water heaters, this study assumes that new home buyers rarely specify the equipment installed. Occupants do have the opportunity to make these purchase decisions when furnaces or other equipment have reached the end of their useful lives and need to be replaced. The exception occurs for condo owners with centrally supplied steam heat since they can rarely choose their heating equipment.

Although several factors affect space-heating demand – furnace efficiency, R-rating of insulation, U-value of windows – the focus is on furnace replacement to define which owner-occupied residences count as “old” for purposes of

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[41] However, calculations of savings potential for space heating are complex and did not fall under the scope of the present study.

[42] For space heating, this study does not make an estimate for emergency replacements. All replacements by occupant-owners who directly pay for their heating energy are classified as Case 1.

determining in which households the occupants have chosen their space heating equipment. Furnace lifetimes are generally estimated at 20 years, so this vintage is used to split the housing stock into older and newer units. This means that more occupant-owned units are affected by PA problems for space heating than for water heating since water heaters are replaced more often.

Table 21 summarizes the distribution of households and energy consumption by PA category (see Annex for details on calculations).

TABLE 21

Principal-Agent classification for space heating by number and share of households and site energy

	End user can choose technology	End user cannot choose technology
End user direct energy payment	Case 1: 50.6 million [48%] [53%], 2.370 PJ Occupant-owned SFRs older than 20 years[a] Occupant-owned older MFRs, older than 20 years, individual space heaters, utilities not included	Case 2: 46.1 million [44%] [40%], 1,802 PJ Most rental units, excluding where utilities included Newer occupant-owned units, excluding condos with central steam heating
End user makes indirect energy payment	Case 3: Negligible Possibly a small number of condos older than 20 years with individual water heaters and space heating fuel included in rent	Case 4: 9.1 million [9%] [8%], 341 PJ Rental MFRs and mobile homes with space heating fuel included in rent Condos with central boilers Newer condos with utilities included

[a] Assumes original space heater has been replaced by owner.

The size of Principal-Agent problems for residential lighting

Data collection

This study used data on electricity used for lighting from an EIA website (2005) that provides more detailed information on electricity consumption than can be found in the main published RECS tables. Additional data on square footage are from the US EIA (2004b) and number of households and data on whether electricity is included in rent are from AHS (2003). The decision tree for classifying residential lighting is the most simple of the four end-uses examined. The fact that light bulbs, whether incandescent or fluorescent, are such a small and inexpensive technology means that end-users almost always control the technology selection.[43] Since this includes virtually 100% of end-users, the only case in which a PA problem arises is that in which end-users do not pay the cost of electricity. The allocation of households to the various cases is discussed below and summarised in Table 22.

Case 1

Over 95% of all households fall into Case 1. This includes all 74 million SFRs although some do report having electricity included in rent or other fees. Case 1 also includes the 8.4 million occupant-owned mobile homes and MFRs and 18.5 million rented mobile homes and MFRs where tenants pay their own electricity bills.

Cases 2 and 4

The number of households where occupants are not able to choose their lighting technologies (*i.e.* the lamp) is negligible.

Case 3

Households in Case 3 consist of the 0.1 million rented mobile homes, 4.3 million rented MFRs, 0.2 million occupant-owned mobile homes, and 0.3 million occupant-owned MFRs where electricity is included in rent or other fees. The total, 4.9 million, is less than 5% of US households.

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[43] Although it should be noted that there are decisions other than the choice of the bulb that are not considered here. For example, decisions regarding the type of socket or lamp fixture, the wiring, switching and other controls have a large impact as does the choice of luminaire type. All these factors are determined over a much longer cycle than the lamps themselves and hence even an owner-occupier (Case 1) is likely to have bought the property after the majority of these decisions have been made by a previous owner or developer. This kind of temporal PA problem is not addressed in this book and therefore, it is likely that this study underestimates the level of energy use affected by PA problems.

TABLE 22

Principal-Agent classification for residential lighting by number and share of households and site energy

	End user can choose technology	End user cannot choose technology
End user makes direct energy payment	Case 1: 101.0 million [95%] [98%], 353 PJ Occupant-owned and rented SFRs Most occupant-owned MFRs and mobile homes Most rental MFRs and mobile homes	Case 2: Negligible
End user makes indirect energy payment	Case 3: 4.9 million [5%] [2%], 8.2 PJ Some rented MFRs and mobile homes Small number of occupant-owned MFRs	Case 4: Negligible

Description of the results

In order to estimate the amount of lighting electricity consumption affected by PA problems, this study assumed that demand for lighting is proportional to household square footage. Using data from the US EIA (2004b), and number of households by housing unit type from AHS (2003), this study estimated the total square footage of the affected MFRs and mobile homes to be just over 5 billion square feet (470 million square metres). This study estimated total square footage for all households to be approximately 221 billion square feet (20.5 billion square metres). Therefore the estimated share of affected square footage is approximately 2%. The share of square footage is lower than the share of households because MFRs and mobile homes are significantly smaller on average than SFRs. This study applied the share of affected square footage to the 100.5 terawatt-hours (TWh) of electricity used for residential lighting (Energy information Administration, 2005). The result, 2.3 TWh (8.2 PJ), is less than 0.1% of total residential site energy. Converted to primary energy (24.2 PJ) the share climbs to a little over 0.1%.

The potential energy savings from eliminating PA problems for residential lighting would be negligible for two reasons. First, the total amount of energy affected is quite small. Second, informational and other barriers appear to be primarily responsible for the low market share of efficient lamps, since the proportion of fluorescent lamps constitutes only 6% of all residential lamps sold in the US, including tubular lamps (Itron, 2004). Even in households with no PA problem, incandescent and halogen bulbs account for a wide majority of lamps sold.

Analysis and implications for all four end-uses

Sensitivity analysis of key assumptions

Because of a lack of data, this study had to make many assumptions to estimate affected energy and energy saving potential for the end-uses described above. Most of these assumptions concerned the allocation of the housing stock into various levels of housing unit type, tenancy status, inclusion of fuel costs in rent or other fees, and main fuel type for space heating and water heating. In some cases, a data point existed for one year and had to be applied to other years for which data were missing. This study also made rough estimates of the energy usage for some end-uses and the effect on consumer choices from removing PA barriers.

This study conducted a sensitivity analysis to investigate the effect of changing the values for the key assumptions. Values were increased or decreased based on reasonable counter-assumptions, and the corresponding changes in energy consumption or savings were noted. The sensitivity analysis and results, organised by end-use, are shown in annex.

The sensitivity analysis indicates that for refrigerators and water heaters, the estimates of the affected energy are quite robust. For space heating, the estimates of affected energy are sensitive to the timeframe used to define "new" units for purposes of determining when original heating equipment is replaced. Additionally, the assumption that new home buyers do not specify their heating-related features may be inflating the estimate of affected energy. With respect to lighting, since the only homes affected are those where utilities are included in rent or other fees, the assumptions concerning the extent to which households reporting utility expenses included in rent are overstated have a large impact on affected energy, particularly applied to MFRs.

Estimates of potential energy savings from removing PA problems were generally more sensitive to the assumptions than the estimates of affected energy. For estimates based on new sales, this is largely due to the relatively narrow range between existing standards and commercially available best-performing models. Thus, a change of a few percent in the assumed efficiency improvement from removing PA problems has a large impact on the results. The stock-wide savings from individually billing the water heating fuel were most sensitive to the assumption that MFR units reporting natural gas included in rent are all accurate. This is due to the greater difference between standard and best-performing natural gas water heaters compared to electric water heaters, the larger number of households with natural gas included, and the assumption that natural gas is the water heating fuel in all households where natural gas is available.

Affected energy use

A summary of the total energy use and affected energy use of the residential end-uses examined is shown in Table 23. Space heating accounts for the largest share (approximately 30%) of primary energy use and from the table it is apparent that PA problems affect a large share of its use. Affected energy consumption of water heaters and refrigerators is also significant. Together, the affected primary energy use of these four end-uses totals roughly 30% of primary residential energy use. The fact that PA problems affect large shares of their energy highlights the importance of standards for reducing energy consumption for these and other end-uses where purchase decisions will be relatively unresponsive to information-based policies and programmes.

TABLE 23

Total energy, Principal-Agent affected energy, and affected energy as shares of end-use energy and all residential site and primary energy in 2005

	Refrigerators	Water heating	Space heating	Lighting	Total, PJ
Site energy, (PJ)	562	1.650	4.465	360	11.297
Primary energy, (PJ)	1.156	2.320	5.313	1.002	15.717
Affected site, (PJ)	141	1.254	2.143	8.2	3.546
Affected primary, (PJ)	392	1.918	2.490	24.2	4.824
Affected share of site by end-use	25.1%	76.0%	48.0%	2.3%	n.a.
Affected share of site total residential	1.2%	11.1%	19.0%	0.1%	31.4%
Affected share of primary residential	2.5%	12.2%	15.8%	0.2%	30.7%

Potential energy savings by removal of Principal-Agent problems

The estimated annual savings from the removal of PA problems from one year's worth of sales are disproportionately larger for water heaters, 6.6 primary PJ/year, than for refrigerators, 0.9 primary PJ/year. The larger value for water heater savings arises due to several factors. First, the per unit energy consumption of refrigerators is much lower than water heaters. Second, with the introduction of a new, significantly more efficient refrigerator standard in 2001, the 2002 average energy efficiency for refrigerators meant that there was less energy to save than for water heaters. With the introduction of new water heater standards in 2004, a savings calculation based on the average 2004 water heater would also yield a smaller estimate of savings (50% or less although still higher than refrigerators). Third, a greater share of water heaters sold each year is destined for housing units affected by PA problems (44% compared to 32%).

Due to the complexity of calculating the savings potential for space heating and the limited scope of this study, this study did not estimate its saving potential. For lighting, the potential savings from eliminating PA problems would be negligible, since information barriers play a much larger role in suppressing sales of efficient bulbs, as evidenced by the low penetration of CFLs in non-affected households.

Implications

One aspect of PA problems that warrants further consideration is the role of information in relation to PA problems. Recall that PA problems arise when certain conditions are met: incentives are misaligned between a principal and his or her agent, the agent's actions incur some cost for the principal, information is asymmetric and monitoring or constraining the agent's actions is impossible or too costly. In some cases, incentives are not fundamentally misaligned but are misaligned in practice due to information barriers. Bear in mind that results have attempted to exclude energy consumption that is affected primarily by information problems.

In Case 2, PA problems are thought to occur because home builders and rental unit owners assume that occupants are unaware of or less sensitive to household operating costs than to the purchase or rental price. In order to recoup the cost of any energy efficiency equipment that is more expensive than standard equipment, buyers or tenants will have to be convinced that higher housing costs will be recovered through energy savings. Prospective tenants may need to see a detailed breakdown of the equipment costs and projected energy savings to accept higher rents. Many programs address information barriers for the end-uses covered in this study: appliance labelling, ENERGY STAR, the Home Energy Rating System, and energy-efficient mortgages. Given the scope of this study, no attempt was made to estimate the extent to which these programs have mitigated the impact of the PA barriers examined here.

With the high prevalence of PA barriers, what policies should be enacted to mitigate them? Recall how PA problems are categorised in Table 1. In Case 2, the "efficiency" problem, excess energy consumption occurs because home builders and landlords buy less efficient equipment for occupants since the occupants will incur the energy bills. Stringent building codes and appliance efficiency standards help to obviate much of the problem. In addition, some cities have energy conservation ordinances that require homeowners to install certain energy-saving features when selling their homes. To the extent that additional cost-effective savings exist beyond standards and codes, the implementation of home labelling programs and the provision of comparative cost estimates for various efficiency measures using local energy prices will help prospective home buyers and renters take utility costs into account when searching for a new residence.

For Cases 3 and 4, as long as occupants are shielded to some degree from the costs of their energy consumption, it will be difficult to persuade them to make significant conservation efforts. For individually-metered units where the landlords pay utility costs, landlords can make it clear to tenants that energy consumption above some baseline level will result in rent increases. The problem may be less tractable for multiple units served by a master meter. In this case, not only are the tenants shielded from the immediate cost of their energy use because the energy costs of master-metered units are usually included in rent, they are also plagued by a tragedy of the commons. Without individual meters there is no practical way to monitor tenants' energy consumption behaviour and enforce co-operation. Laws requiring individual sub-metering will help to ensure that future housing stock is not affected by this problem, but retrofitting buildings with master-metered natural gas is cost prohibitive. Individual Btu meters for central hot water and steam heating systems are also expensive and may not turn out to be cost-effective for the energy savings they stimulate.

Conclusion and recommendations

The analysis reveals some important findings. First, price signals alone may have a limited effect on inducing energy conservation in the residential sector because a large share of energy is consumed by end-users who either have little or no control over the efficiency of energy-using equipment (Case 2) or who are shielded to some extent from the costs of their energy consumption (Cases 3 and 4).

Table 23 highlights the fact that approximately 30% of residential site energy use falls into these categories.

If price signals are not an effective means of eliciting energy conservation in these households, what programs or measures are best tailored to overcome the PA barriers analysed in this report? In Table 24 the shares of each end-use's energy consumption is grouped by case. The bulk of the energy affected is characterised by Case 2. Programmes oriented toward the provision of information could overcome these barriers to some extent. Existing ENERGY STAR and HERS ratings for new homes (see section on 'policy context'), in addition to appliance labels, help by convincing home builders that buyers will pay more attention to efficiency and enable them to pass through costs for better equipment. However, it is difficult to imagine how such a system could be applied cost-effectively to the stock of existing and new rental units. Appliance standards and building codes offer one way to address the PA barriers in both rental and occupant-owned housing markets. Information programmes may then be used to induce savings beyond minimum standards.

Table 24

Summary of site energy end-use affected by Principal-Agent typology

Case 1: No PA problem		Case 2: Efficiency problem	
Refrigerators:	72%	Refrigerators:	25%
Water heating:	23%	Water heating:	68%
Space heating:	53%	Space heating:	40%
Case 3: Usage and efficiency problem		**Case 4: Usage problem**	
Refrigerators:	<1%	Refrigerators:	3%[a]
Water heating:	negligible	Water heating:	9%
Space heating:	negligible	Space heating:	8%

[a] Refrigerators are an exception since, no usage problem exists in Case 4 assuming same agent (*e.g.*, landlord) chooses technology and pays for energy.

The households that comprise Case 4 for a given end-use face a different obstacle. These households are either master metered or individually metered, but the landlord pays the utilities nevertheless. This study assumed that landlords have an incentive to invest in reasonably efficient equipment, but this may not be true if landlords believe that they can easily pass through higher energy costs to tenants. Thus, it is likely that standards help to increase efficiency in this case as well. Outreach programs to landlords could help to ensure that tenants are informed that wasteful energy consumption can lead directly to higher rents. However, in units that are master metered, there is a tragedy of the commons problem that will be difficult to overcome without sub-metering.

Among the end-uses examined, the affected energy use for water heating and space heating accounts for almost 30% of all residential site energy. These end-uses may deserve particular attention for overcoming PA barriers. For example, one study on an energy efficiency design assistance program found that the program had very little success convincing developers of new MFR units to install gas-fired forced air or hydronic heating rather than electric baseboard systems because developers did not think they could pass the costs through to new tenants (Kelsey and Vance, 2002).

Another conclusion is that existing MEPS programmes need to be continually strengthened. Over time, this can help to reduce PA problems.

Finally, the current incentives for builders should be continued beyond the current 3-year window. In addition, the US government should explore ways of extending such an incentive scheme to other principals.

Data on the differences in energy consumption for various end-uses by PA case (see Table 1) would be helpful for deriving better estimates of the impact of tenancy status and inclusion of utilities in rent on energy consumption. RECS should provide breakouts of energy consumption by tenancy-status as well as unit type and that future RECS surveys include questions on which fuels are included in rent or other fees. Future studies could also help to elucidate the effectiveness and cost of standards compared to information-oriented programs for Case 2 households.

SPACE HEATING IN RENTED HOUSES IN THE NETHERLANDS

This case study quantifies Principal-Agent problems for space heating in rented houses in the Netherlands. Different kinds of PA problems arise in this sector. The most common occurs when the party paying the energy bill (usually the dwelling occupant) is not the same as the one choosing the technology. In this case, the supplier of energy-using equipment may provide less energy-efficient equipment than if he or she was not shielded from the price of energy. This may lead to a situation where the dwelling occupant would use more energy than they would if they had chosen the appliances themselves.

Energy use for space heating in the rental sector in the Netherlands and energy efficiency policies

Energy use in the rental sector in the Netherlands

Table 25 and Figure 22 (National Statistics Office, 2007) show energy consumption in the residential sector in the Netherlands from 1993-2002.

As Figure 22 shows, electricity consumption in the residential sector increased by 27% from 1990 to 2002. The historic increase in electricity consumption can be explained by an increase in the number of appliances per household, including computers, printers, televisions, video players, and communication equipment.

Natural gas is the main energy source for space heating and hot water (95%) in the Netherlands. Despite growth in the housing stock, natural gas use decreased by 5% from 1990-2002. has grown. However, the decline in natural gas use can be attributed to several factors: 1) improved quality of the existing housing stock; 2) increased use of insulation and higher-efficiency condensing boilers; 3) demolition of old houses that had a relatively high energy demand; and 4) implementation of a new energy performance standard (EPN) beginning

TABLE 25

Final and primary energy consumption (corrected for temperature) in the residential sector (1993-2002)

	Final energy use		Primary energy use			
	Electricity	Natural gas, temperature corrected	Natural gas	Electricity	Oil, coal	Total
	(mln kWh)	*(mln m^3)*	*(PJ)*	*(PJ)*	*(PJ)*	*(PJ)*
1993	17 900	11 532	365	158	17	540
1994	18 500	11 619	368	163	15	546
1995	19 700	12 058	382	173	13	568
1996	20 000	12 254	388	176	13	577
1997	20400	11 796	373	179	12	565
1998	20 800	11 548	366	183	11	559
1999	21 350	11 873	376	177	11	564
2000	21 800	11 902	377	180	10	567
2001	22 100	11 533	365	183	11	559
2002	22 800	10 901	345	189	12	546

in 1995. This standard became more stringent in 1998 and 2000. As a result, the average annual natural gas consumption per newly built house declined from 1 500 m^3 in 1995 to 1 200 m^3 in 2000 (Joosen *et al.*, 2004).

Such trends are expected to continue for the period 2005-2020 (ECN 2005). Residential electricity consumption is expected to increase between 7.5% and 27% in the period 2000-2020 (from 106 PJ in 2020 to 114 PJ–135 PJ in 2020) (ECN, 2005). Natural gas use is expected to continue to decline between 10% and 19% for the period 2000-2020, from 349 PJ in 2000 to 283 PJ–315 PJ in 2020 (ECN, 2005).

Figure 23 shows the average annual natural gas consumption per household for the period 1975-2004. The data shows that that there is a considerable decline

FIGURE 22

Electricity and natural gas use of the residential sector (1990-2002, temperature corrected)

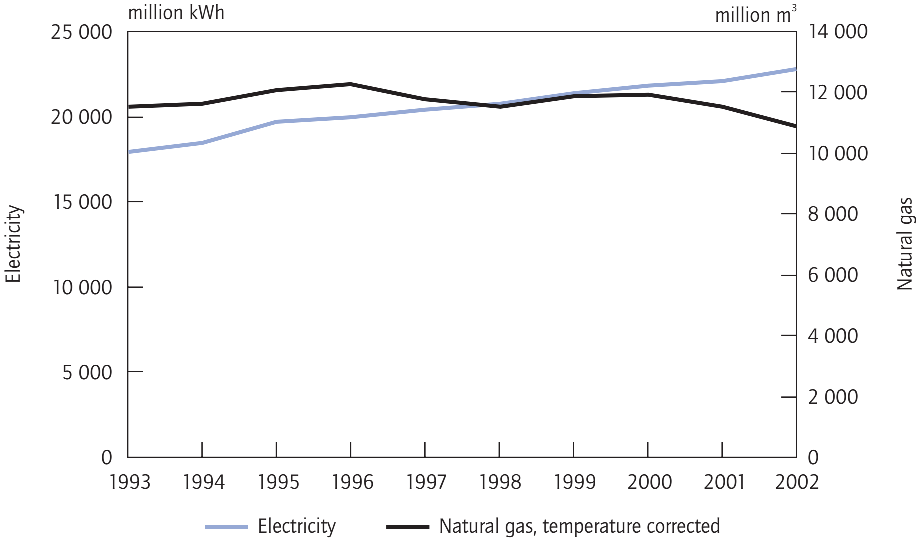
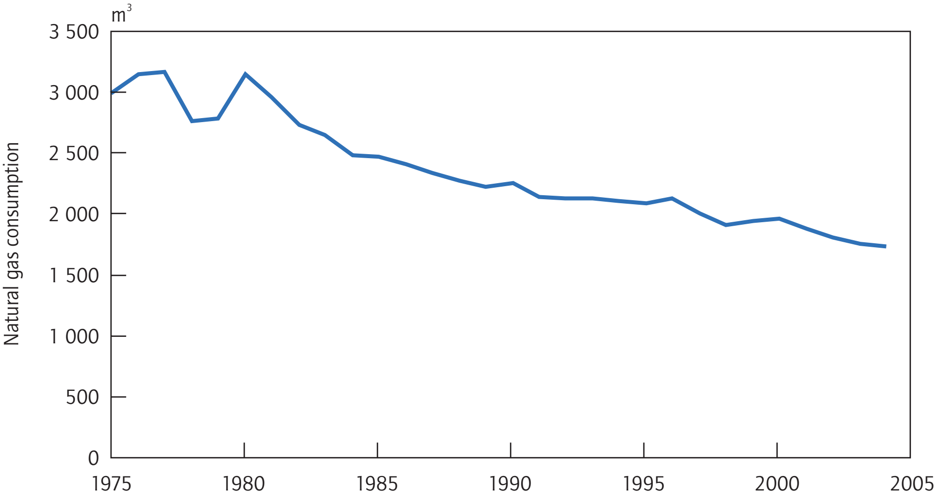


FIGURE 23

Average annual natural gas consumption per household (1975-2004)



Source: EnergieNed, 2005.

in natural gas consumption during this period. As noted above, one of the reasons for this decline is an overall improvement in the energy efficiency of the existing housing stock.

Table 26 shows the average annual natural gas consumption for space heating, hot water, and cooking. The table shows that space heating accounts for 74% of the total natural gas consumption in the residential sector. This corresponds to primary energy use of approximately 256 PJ.

The table also shows that the decrease in energy demand for space heating per household caused the decline in average annual natural gas consumption per household. Energy efficiency measures such as the increased use of insulation and energy-efficient boilers in existing buildings, as well as the implementation of the energy performance standard for newly built houses beginning in 1996, contributed to the decline in energy demand for space heating.

Energy efficiency policies

The Netherlands has implemented energy efficiency policies for new and existing buildings since the late 1990s. Current policies include the Energy Performance Norm (EPN) which targets new construction and the Optimal Energy Infrastructure Programme (OEI) which targets new and existing construction.

All new residential buildings must meet the Energy Performance Norm (EPN). Builders can choose which measures to implement to achieve this binding energy performance level. Since 2000, buildings must be designed so that natural gas demand per year for heating, hot water and cooking for an average-sized house does not exceed 1 000 m^3.

The goal of the OEI, established in 1997, is to integrate energy efficiency and sustainable energy into all stages of a residential construction project. The OEI offers cost-benefit analysis to reduce CO_2 emissions, subsidies for energy studies, information dissemination, a help desk, and the Energy Performance of the Location (EPL), a voluntary benchmark.

Past energy efficiency policies for existing construction include the Energy Premium Regulation (EPR), and the Energy Performance Advice (EPA). EPR,

TABLE 26

Average annual natural gas consumption per household for space heating, hot water and cooking (1980-2004)

Year	Average annual domestic gas consumption (Nm^3)						
	Total	Heating	%	Hot water	%	Cooking	%
1980	3 145	2 780	88%	305	10%	80	3%
1981	2 965	2 605	88%	280	9%	80	3%
1982	2 730	2 385	87%	270	10%	75	3%
1983	2 650	2 315	87%	260	10%	75	3%
1984	2 480	2 160	87%	245	10%	75	3%
1985	2 475	2 161	87%	245	10%	70	3%
1986	2 405	2 075	86%	260	11%	70	3%
1987	2 340	1 900	81%	370	16%	70	3%
1988	2 275	1 830	80%	375	16%	70	3%
1989	2 220	1 755	79%	395	18%	70	3%
1990	2 250	1 780	79%	400	18%	70	3%
1991	2 140	1 670	78%	400	19%	70	3%
1992	2 125	1 700	80%	360	17%	65	3%
1993	2 130	1 701	80%	365	17%	65	3%
1994	2 105	1 675	80%	365	17%	65	3%
1995	2 090	1 660	79%	365	17%	65	3%
1996	2 130	1 690	79%	375	18%	65	3%
1997	2 000	1 560	78%	375	19%	65	3%
1998	1 910	1 475	77%	370	19%	65	3%
1999	1 940	1 500	77%	375	19%	65	3%
2000	1 965	1 525	78%	375	19%	65	3%
2001	1 875	n.a.		n.a.		n.a.	
2002	1 812	n.a.		n.a.		n.a.	
2003	1 759	n.a.		n.a.		n.a.	
2004	1 736	1 290	74%	383	22%	63	4%

Source: EnergieNed, 2005; Bak, 2000.

implemented in 1999, provided tax incentives for implementing energy saving measures. In 2003, the government converted the tax incentives to subsidies but subsequently cancelled it because of free rider problems. In total EUR 54 million in subsidies are being given each year to help the consumers buy energy-efficient household appliances and to promote the use of energy-efficient technologies and renewable energy in households built prior to January 1998. In 2003, the EPR for energy efficiency was cancelled because part of the budget was subsidizing measures that would have been implemented without the subsidy ("free riders"). Under the voluntary EPA programme, the energy performance of a building was modelled and advice given to support energy-saving measures. In 2006 the EU Directive on Energy Certificates replaced the EPA.

These policies have been effective in improving the energy efficiency in the residential sector in the Netherlands. Nevertheless, the government needs to evaluate policies to prevent free riders. The government also needs to institute stronger norms for existing residential buildings.

The size of Principal-Agent problems

Data collection

Data was obtained on the penetration of implemented energy measures from the quality registration of the housing stock (KWR, 2000).[44]

The study estimated the division of the data between the privately owned, private rent and public rent segments because the data does not contain this information. In addition, there is no data on energy bill payment responsibility (owner or tenant).

Table 27 presents data on the Dutch housing stock by various market segments. Because housing policy in the Netherlands stimulates home ownership, housing

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[44] This house survey is organised every year in the Netherlands to determine the quality of the housing stock. It is carried out on behalf of the Dutch Ministry of Housing, Spatial Planning and the Environment.

associations often offer tenants the opportunity to buy their rented dwelling at a reasonable price. This is why the rental sector share decreased from 55% in 1990 to 46% in 2002.

The age and size of a house are other important factors in determining the housing stock's energy consumption and in analysing PA problems. The age of a house indicates to what extent houses are insulated. The size of a house will indicate how much energy is consumed.

TABLE 27

Housing stock (1990-2005)

Year	Housing stock (*1 000 houses)			
	Total	Rent (public)	Rent (private)	Privately owned
1990	5 802	40.5%	14.2%	45.3%
1998	6 441	36.6%	11.5%	51.9%
1999	6 522	36.3%	11.2%	51.3%
2000	6 590	35.7%	11.5%	51.5%
2001	6 651	35.3%	n.a.	n.a.
2002	6 711	35.0%	11.0%	54.0%
2003	6 764	n.a.	n.a.	n.a.
2004	6 810	n.a.	n.a.	n.a.
2005	6 861	n.a.	n.a.	n.a.

Source: National Statistics Office, 2007.

Table 28 and Table 29 present characteristics of the housing stock in 2000. Based on the information in these tables, the following conclusions can be made: 1) houses in the social rental sector were mainly built during the 1950s and 1960s; 2) houses in the private rental sector were mainly built in the same period and in the period before 1946; 3) small houses such as terraced houses and apartments represent the largest share in the social rental sector; and 4) the largest part of housing built before 1946 is privately owned.

TABLE 28

Building age of the housing stock in the Netherlands in 2000

Number of houses in 2000		Building segment		
Building age	Total	Privately owned	Social rental	Private rental
–1946	23%	13%	4%	5%
1946 t/m 1965	24%	9%	12%	2%
1966 t/m 1975	20%	10%	8%	2%
1976 t/m 1979	5%	4%	1%	0%
1980 t/m 1987	13%	6%	6%	1%
1988 t/m 1991	6%	3%	2%	0%
1992 t/m 1995	5%	3%	2%	0%
1996 +	5%	4%	1%	0%
Total	**100%**	**52%**	**36%**	**12%**

Number of houses in 2000		Building segment		
Building age	Total	Privately owned	Social rental	Private rental
–1946	1 498 692	868 147	277 778	352 767
1946 t/m 1965	1 563 814	621 104	808 333	134 377
1966 t/m 1975	1 311 760	661 720	509 925	140 114
1976 t/m 1979	312 091	236 980	64 097	11 014
1980 t/m 1987	832 181	377 139	377 315	77 726
1988 t/m 1991	379 217	227 504	126 170	25 544
1992 t/m 1995	340 576	220 655	101 816	18 106
1996 +	339 232	238 345	85 191	15 696
Total	**6 577 563**	**3 451 594**	**2 350 625**	**775 344**

Source: KWR, 2000.

TABLE 29

Housing types in the Netherlands in 2000

Number of houses in 2000		Building segment		
Building Type	Total	Privately owned	Social rental	Private rental
Detached house	15%	14%	0%	1%
Semi-detached house	12%	10%	2%	1%
End-of terrace house	17%	9%	6%	1%
Terraced house	26%	13%	10%	2%
Apartment building	25%	5%	15%	5%
Maisonnette	5%	1%	2%	1%
Total	**100%**	**52%**	**36%**	**12%**

Number of houses in 2000		Building segment		
Building type	Total	Privately owned	Social rental	Private rental
Detached house	1 011 065	926 682	18 430	65 953
Semi-detached house	819 257	664 917	100 500	53 841
End-of terrace house	1 097 700	602 366	413 012	82 322
Terraced house	1 687 684	852 930	680 532	154 222
Apartment building	1 655 366	311 604	996 768	346 994
Maisonnette	316 998	97 168	145 858	73 972
Total	**6 588 070**	**3 455 668**	**2 355 099**	**777 303**

Source: KWR, 2000.

Table 30 presents estimates of the number of houses and useful floor space corresponding to the various cases of the PA problem for 2004 using data from KWR (2000).

TABLE 30

Estimated number of houses and useful floor space per case

	End user chooses technology	End user does not choose technology
End user pays the energy bill	Case 1: No problem owned houses: 3.6 mln (53%) Useful floor space: 440 mln m^2 (59%)	Case 2: Efficiency problem Rented houses: 3.2 mln (47%) Useful floor space: 306 mln m^2 (41%)
End user does not pay the energy bill	Case 3: Usage and efficiency problem negligible	Case 4: Usage problem Difficult to quantify

Source: KWR, 2000; National Statistics Office, 2007.

Description of the results

The housing stock in the Netherlands consists of three segments: 53% privately owned, 35% social rental, and 11% private rental. This means that in a situation where all tenants are responsible for paying the energy bill, PA problems could affect at most 47% of the houses in the residential sector. In this study, the focus is on Case 2, suggesting that the person responsible for paying for the energy saving measure (the owner of the house) does not profit from a lower energy bill. The percentage of the housing stock falling under Case 2 is actually lower because in some cases the energy bill is included in the rent and paid by the owner of the house (Case 4). However, there is no data available on which share of the houses in the rental sector fall under Case 2 and which fall under Case 4.

The number of houses that have already implemented energy efficiency measures to reduce the energy use for space heating is presented in Table 31. As is shown in the table, the private rental segment has the least penetration of energy efficiency measures. Furthermore, the table shows greater penetration of highly efficient condensing boiler in the privately owned sector compared with the rental sector.

The information in Table 31 would lead us to conclude that there is some difference in the implementation of energy efficiency measures between owned and rented houses. However, in the absence of any other information, the study makes the conservative assumption that the energy demand for space heating in rental houses is the same as privately owned on a square metre basis.

TABLE 31

Energy measures already implemented in the residential sector

Penetration degree in 2000		Building segment			Insulation degree in 2004
Measure	**Total**	**Privately owned**	**Social rental**	**Private rental**	**Total**
Roof insulation	64%	70%	59%	40%	67%
Wall insulation	50%	52%	55%	29%	54%
Floor insulation	35%	39%	30%	21%	38%
Insulated glazing	66%	70%	67%	48%	73%
Boiler (improved yield)	49%	43%	60%	54%	n.a.
Condensing boiler (high yield)	38%	47%	26%	25%	n.a.

Source: KWR, 2000; Milleucentral, 2004.

Table 32 shows the energy consumption that might be affected by PA problems. Note that other factors, including behaviour, play an important role in energy consumption. Their impact is discussed in the section on the sensitivity of the results.

TABLE 32

Estimated energy use for Cases 1–4, space heating in the residential sector

	End user chooses technology	End user does not choose technology
End user pays the energy bill	Case 1: No problem Energy use for space heating in owned houses: 151 PJ (59%) natural gas consumption: 4 769 mln m^3	Case 2: Efficiency problem Energy use for space heating in rented houses: 105 PJ (41%), natural gas consumption: 3 319 mln m^3
End user does not pay the energy bill	Case 3: Usage and efficiency problem Negligible Case 4: Usage problem	Difficult to quantify

Analysis and implications

Approximately 47% of the housing stock in the Netherlands is rented. The study estimates the corresponding energy consumption for space heating is 105 PJ. To determine the energy use that is affected by Case 2 described above (*i.e.* investors do not receive the financial return from investing in energy-efficient technologies), the study analysed information on the penetration of energy efficiency measures (Table 31). The penetration of energy efficiency measures in the social rental sector is in general comparable to that in the private rental sector. One explanation for this could be that energy efficiency policies that have been implemented since the 1970s have to a large extent overcome split incentive problems. These policies include urban renovation programmes, energy efficiency subsidy programmes of the 1980s and 1990s (abolished in 2003) and the covenant between housing associations and the government.

In the private rental sector where split incentives were observed, the penetration of insulation measures is considerably lower than in the privately owned sector. Assuming that 20% of the houses can be additionally insulated, with an energy saving of 50-75% per house, the affected energy consumption is about 2-4 PJ.

Table 31 shows a higher penetration of high yield condensing boilers in the privately owned sector and a higher penetration of the improved yield boilers in the social and private rental sectors. The study concludes from the data in Table 31 that the social and private rental segments prefer the boiler with an improved yield, and the privately owned sector prefers the high efficient condensing boiler. The higher investment cost of the high yield condensing boiler and split incentives are likely to cause this difference. The study estimates the energy consumption affected by split incentives to be about 2 PJ (assuming 20% of the houses in the rental segment could have a high yield boiler, and that high yield boilers save 10% more energy compared with boilers with an improved yield). Alternatively, based on selected key measures, the study estimates the effect at 4-6 PJ, which corresponds to approximately 2% of the total energy use for space heating.

Limitations of the study and sensitivity analysis

The analyses are based on available data about implementation degree of several energy saving measures in the various segments of the housing stock. However, the study found no data confirming which party pays the energy bill in the rental sector. The study assumed that the tenant pays the energy bill (Case 2). Other factors in addition to useful floor space that determine the energy consumption for space heating – such as behaviour – are not taken into consideration.

The analysis assumed that space heating energy use per m^2 is similar across housing segments. However, it is difficult to estimate accurately the energy consumption for space heating in different types of households because this consumption depends on many factors. These factors include the degree of insulation, the energy efficiency of the heating system and the size of the house, as well as the behaviour of the consumers. An important conclusion of this study is that people with higher incomes, who live mostly in larger privately owned houses, tend to consume more energy (with more rooms heated during a longer period at a higher temperature) than the average household. Therefore, the energy use for Case 1 may have been under estimated and potentially over estimated energy use in Cases 2-4 (Table 32).

A factor that may counter this under estimation in Cases 2-4 is in the market rental accommodation for elderly people. The RIGO (2005) study shows that elderly people in social terraced houses have higher energy use (higher heating temperature for a longer time during the day).

Conclusions and recommendations

The results show that a PA problem is present in space heating in rented houses in the Netherlands affecting at least 105 PJ/year. The investor in the heating system (house owner) may not be the same person as the one paying the energy bill. This can lead to choices of less expensive, non energy-efficient space heating systems.

The analysis shows that 41% of the energy consumption for space heating in the residential sector might be affected by this PA problem. The implementation of energy saving policies since the 1970s has reduced the energy use affected by the PA problems.

SET-TOP BOXES: ENERGY USE AFFECTED BY THE PRINCIPAL-AGENT PROBLEM IN THE UNITED STATES

This case study investigates whether Principal-Agent problems exist in the television set-top box market in the United States. A set-top box is an electronic device that receives a video signal and converts it for display on a television or, increasingly, on a computer monitor. Set-top boxes are one device among a broader category of consumer electronics.

FIGURE 24

A set-top box

Consumer electronics and energy use in the set-top box market

The electricity consumption of consumer electronics is a growing concern to United States policy makers. Through the 1970s and 1980s the numbers of these products and the hours they were used increased rapidly.

In the mid 1990s, ENERGY STAR (see Chapter 9) launched its first programs to reduce the energy consumption of televisions and VCRs and, later, audio equipment and telephones. In 2000, ENERGY STAR initiated program to promote energy-efficient set-top boxes but, for reasons described below, ENERGY STAR terminated the program in 2005. In mid 2007 ENERGY STAR began discussions with stakeholders to establish a new voluntary program to encourage energy-efficient set-top boxes.

The Department of Energy (2006) began reporting electronics as a separate category (see Table 33) which, in 2006, was responsible for 2.9% of residential electricity use. Home computers were responsible for an additional 0.6%, totalling 3.5% of residential electricity energy use.

The uncertainty and rate of growth in the consumer electronics sector is revealed by a more detailed study in 2007. This study (Roth *et al.,* 2007) estimated that consumer electronics were responsible for about 11% of residential energy use.[45] This corresponds to about 1.7% of total U.S. primary energy consumption in 2006.

The television set-top box is a key consumer electronics product. A set-top box is an electronic device that receives a video signal and converts it for display on a television or, increasingly, on a computer monitor.[46] Originally, the video signal came through cable networks. Because of technical advances, information is now also provided via satellite and the internet. Regardless of the technology, some sort of separately powered electrical device must reside near the television to make the signal conversion.[47] The box typically contains proprietary circuitry and encryption to ensure that customers do not access programs for which they did not pay.

A television set-top box consumes significant energy because it is constantly drawing power. Many homes have two boxes, which can consume as much energy as a refrigerator. The number of homes relying on set-top boxes to receive the television signal is also increasing rapidly. For these reasons, the energy use of set-top boxes has become an important issue.

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[45] The report omitted the contribution of digital televisions. If one assumes that these are responsible for an additional 1%, then the total is 12%.

[46] Other names for this product include “decoder”, “cable box”, and “digital television adapter”.

[47] The device’s name suggests that the box sits on top of the television; in fact most boxes now sit to the side of the televisions so a more accurate name would be “set-side box”.

TABLE 33

Residential sector energy consumption in the United States (2006)

	Natural Fuel		LPG	Other Ren.		Site	Site		Primary	Primary	
	Gas	Oil		Fuel (1)	En. (2)	Electric	Total	Percent.	Electric (3)	Total	Percent.
Space heating (4)	3.50	0.82	0.29	0.10	0.41	0.48	5.60	48.80%	1.53	6.64	31.50%
Water heating	1.15	0.12	0.05	n.a.	0.02	0.41	1.76	15.40%	1.31	2.66	12.60%
Lighting	n.a.	n.a.	n.a.	n.a.	n.a.	0.79	0.79	6.90%	2.52	2.52	12.00%
Space cooling	0.00	n.a.	n.a.	n.a.	n.a.	0.74	0.74	6.40%	2.34	2.34	11.10%
Refrigeration (5)	n.a.	n.a.	n.a.	n.a.	n.a.	0.53	0.53	4.60%	1.67	1.67	7.90%
Electronics (6)	n.a.	n.a.	n.a.	n.a.	n.a.	0.33	0.33	2.90%	10.60	1.06	5.00%
Wet clean (7)	0.07	n.a.	n.a.	n.a.	n.a.	0.30	0.37	3.30%	0.96	1.03	4.90%
Cooking	0.21	n.a.	0.03	n.a.	n.a.	0.22	0.47	4.10%	0.71	0.95	4.50%
Computers	n.a.	n.a.	n.a.	n.a.	n.a.	0.07	0.07	0.60%	0.22	0.22	1.10%
Other (8)	0.10	n.a.	0.17	n.a.	0.00	0.18	0.45	1.00%	0.58	0.85	4.00%
Adjust to SEDS (9)	n.a.	n.a.	n.a.	n.a.	n.a.	0.35	0.35	3.10%	1.11	1.11	5.30%
Total	**5.03**	**0.94**	**0.54**	**0.10**	**0.43**	**4.41**	**11.46**	**100.00%**	**14.02**	**21.07**	**100.00%**

Note(s):
1) Kerosene (0.09 quad) and coal (0.01 quad) are assumed attributable to space heating;
2) Comprised of (0.41 quad) wood space heating, (0.02 quad) solar water heating, (less than 0.01 quad) geothermal space heating, and (less than 0.01 quad solar pv.;
3) Site-to-source electricity conversion (due to generation and transmission losses) = 3.18;
4) Includes (0.26 quad) furnace fans;
5) Includes (1.27 quad) refrigerators and (0.40 quad) freezers;
6) Includes (0.45 quad) colour television (0.61 quad), and other office equipment;
7) Includes (0.10 quad) clothes washers, (0.07 quad) natural gas clothes dryers, (0.78 quad) electric clothes dryers, and (0.08 quad) dishwashers. Does not include water heating energy.;
8) Includes small electric devices, heating elements, motors, swimming pool heaters, hot tub heaters, outdoor grills, and natural gas outdoor lighting;
9) Energy adjustment EIA uses to relieve discrepancies between data sources. Energy attributable to the residential buildings sector, but not directly to s pecific end-uses.
Source(s): EIA, AEO 1999, Jan. 1999, Tables A2, p.113-114 - EIA, AEO 2006, Feb. 2006, Tables A2, p.134-136, Table A4, p.139-140, and Table A17, p.159 - BTS/A.D.Little, Electricity Consumption by Small End-Users in Residential Buildings, Aug. 1998, Appendix A for residential electric end-uses. The Department of Energy 2006.

Cable television still dominates the US market with about 60% of the homes relying on cable service (The National Cable and Telecommunications Association, 2007). Simple cable connections do not require a set-top box. But customers seeking "premium" content still need boxes. About 75% of cable customers have premium subscriptions (The National Cable and Telecommunications Association, 2007) and require boxes. Televisions relying on satellite internet – now serving about 40% of US homes (The National Cable and Telecommunications Association, 2007) – always need boxes.

The service provider provides the consumer with a box as part of the subscription in nearly all cases. However, recent legislation now requires cable television providers to allow customers to purchase their own set-top boxes.[48] Cable service providers must give customers a smart card, called a "CableCard", which fits into the purchased set-top box.[49] Television manufacturers offer some televisions with a card slot built in so that no box is needed. This option has not been popular with consumers and uptake has been slow; as of 2006 only 3% of digital televisions sold were equipped with this feature (Taub, 2006). Cable service providers have also been slow in providing cards and sometimes still require boxes. Manufacturers are now considering discontinuing this option. The leading consumer magazine in the United States, *Consumer Reports*, advised its readers to continue renting boxes from service providers rather than purchase boxes (Consumer Reports, 2005). Based on sales trends, consumers probably own less than 1% of the entire stock of set-top boxes.

The personal video recorder ("PVR" but confusingly also called the "DVR") is contains a hard-disk capable of recording and replaying video content broadcast though cable, satellite or internet. Most PVRs are bundled with set-top boxes and offered to consumers as a higher-priced service option. However, some PVRs are sold separately as a stand-alone device (notably the "TiVo").

In 2007 there were roughly 148 million set-top boxes in the United States, which translates into roughly 1.5 boxes per home. Table 34 shows a breakdown by technology.

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[48] Consumers receiving video signals via satellite and telephone are not affected by this legislation.

[49] This system is already widely used in Europe.

FIGURE 25

A television and set-top box

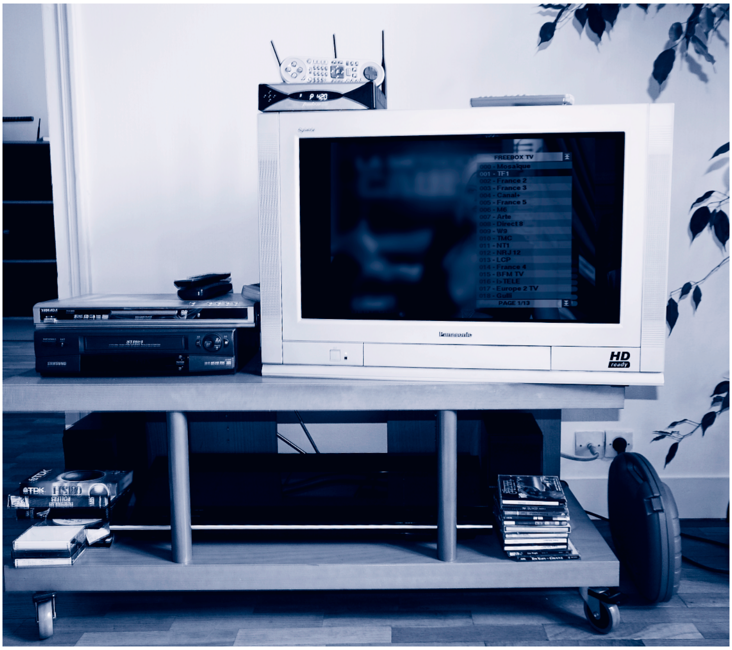


TABLE 34

Stock of set-top boxes in 2006 (millions)

	Cable	Satellite	Stand Alone	Total
Analog	28	n/a	n/a	28
Digital	42	61	n/a	102
High definition digital	1	1.4	n/a	2
Digital PVR*	4	6	1.5	12
High definition PVR*	1	1.4	n/a	2
Total	**77**	**70**	**2**	**148**

*A PVR – "Personal Video Recorder" – is a hard disk drive capable of recording video content from cable, satellite, or internet sources.
Source: adapted from Roth and McKenney, 2007.

Energy use in the set-top box market

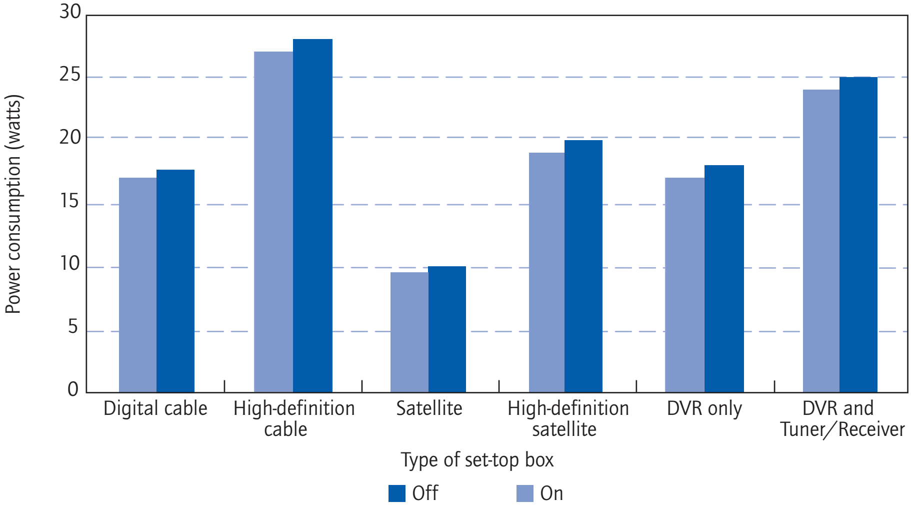
Set-top boxes operate in several modes, each drawing a different level of power. Recent measurements for the two principal modes are shown in Figure 26. Set-top boxes typically draw 10–25 watts, depending on features and technology. A high-definition (HD) unit typically draws more power than standard definition. Set-top boxes with a hard-disk also draw more power than those without disks.

Total energy use of set-top boxes in 2007 will be about 72 PJ/year. This corresponds to 1.5% of U.S residential electricity use. Table 35 shows the contribution of each type of set-top box to total electricity consumption.

An unusual feature of set-top boxes is that their power consumption does not significantly drop when switched to the "off" or "standby" modes (see Figure 26). The service providers want the capability to download program information (schedules) at any time, perform service upgrades, and maintain security. The box must be sufficiently operational (or "awake") in order to receive signals from the provider and to perform these operations. The "off" switch has an insignificant impact on energy consumption and the key determinant of set-top box energy use is the type and number of boxes in US homes.

FIGURE 26

Field measurements of set-top boxes



Source: Adapted from Foster (2005).

TABLE 35

Annual electricity consumption of set-top boxes in 2007

	Cable (TWh/yr)	Satellite (TWh/yr)	Stand Alone (TWh/yr)	Total (TWh/yr)
Analog	4	n.a.	n.a.	4
Digital	5	7	n.a.	12
High Definition Digital	0	0	n.a.	0.4
Digital PVR*	1	1	0.4	3
High Definition PVR*	0	1	n.a.	1
Total	**10**	**9**	**0.44**	**20**

* A PVR – "Personal Video Recorder" – is a hard disk drive capable of recording video content from cable, satellite, or internet sources.
Source: Roth *et al.*, 2007.

The service provider selects the set-top box and the consumer pays the electricity bill. The service provider seeks to minimise the cost of boxes even if it is to the detriment of energy efficiency.[50] Thus, there is a classic PA problem — between the service provider and consumer.

ENERGY STAR established and then abandoned a voluntary efficiency program for set-top boxes. Box manufacturers lacked the incentive to offer efficient boxes meeting ENERGY STAR specifications because their customers — the service providers — had no incentive to purchase them.

A contrasting model is the mobile phone network. An advanced mobile phone is capable of performing many of the same functions as the set-top box but with less than 1% of the power consumption. With mobile phones, however, the manufacturers and service providers share the goal to maximise energy efficiency because it translates into longer battery life and enhanced telephone performance.

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[50] In the "International Workshop on Saving Energy in Set-Top Boxes" (sponsored by the International Energy Agency in May 2003 in Paris) a service provider acknowledged that these decisions had been made and that, during one period, it had even instructed a box manufacturer to remove efficient components as a means of achieving lower costs.

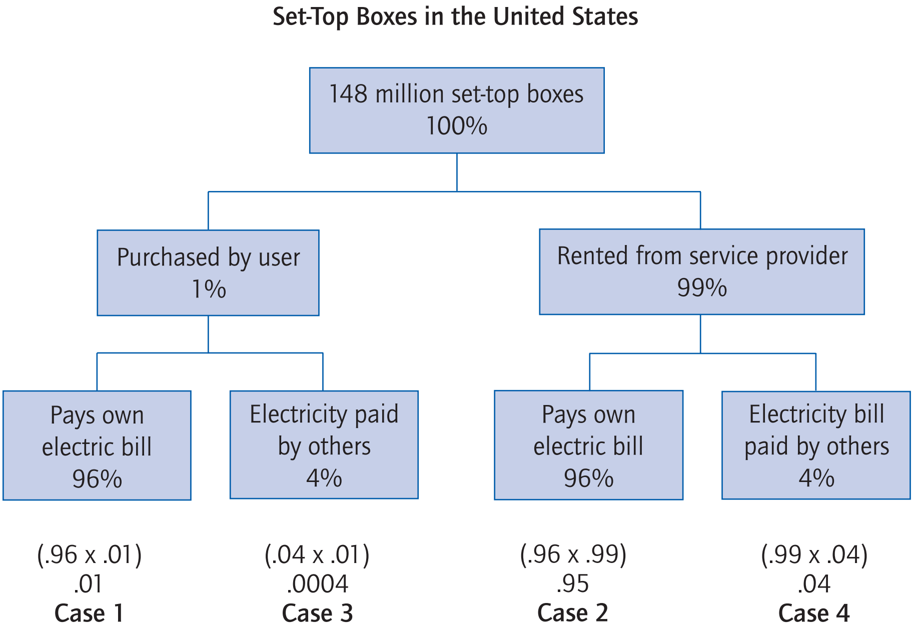
The size of Principal-Agent problems

Data collection

The set-top box energy use affected by PA problems was calculated by estimating the number of set-top boxes in the four cases described in the Methodology chapter. The possible purchasing and payment situations are calculated based on the disaggregations developed in Chapter 3. It assumes that 148 million set-top boxes were in operation in 2006.[51]

FIGURE 27

Disaggregation of set-top box ownership



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[51] Another market failure, asymmetric information, appears here. The boxes do not have energy labels nor is there any comprehensive source of this information. The Consumer Reports article (Consumer Reports, 2005) did not even mention energy use. This study did not address the energy affected by other market failures, such as asymmetric information or externalities.

The initial split reflects the rent/purchase groups representing 99% and 1%, respectively. The next split accounts for the fraction of customers in each group that pay for their electricity use. Survey data indicate that in about 4% of the homes, the occupants do not pay for electricity (Energy Information Administration, 1999). It is assumed that this fraction applies to homes where the boxes were purchased and where they were rented. In other words, consumers who do not pay for their electricity use will be just as likely to rent set-top boxes. These sub-groups are listed in the lower boxes in Figure 27. The calculations of the fractions for each category are shown at the bottom of Figure 27.

Each of the lower boxes also corresponds to one of the affected populations described in the methodology chapter and can be transferred directly into Table 4. About 141 million set-top boxes fall into Case 2 – an efficiency problem. The total number of boxes affected by all PA problems is the sum of the populations in Cases 2, 3 and 4, that is, about 147 million. This corresponds to about 99% of the set-top boxes in use.

The average energy use of the boxes is likely the same in all of the cases (or at least there is no reason to assume otherwise). For this reason, the 72 PJ can be allocated to each of the cases proportionally to the affected population. The results are shown in Table 36.

TABLE 36

Breakdown of affected stock based on end-user's perspective (% of total national set-top box electricity consumption) and PJ[52]

	End user can choose technology	End user cannot choose technology
End user pays the energy bill	Case 1: No PA problem Stand alone units (1% of stock) 0.7 PJ	Case 2: Efficiency problem All cable and satellite boxes (95% of stock) 68.4 PJ
End user does not pay the energy bill	Case 3: Usage and efficiency problem Stand alone boxes in rented units (0.04% of stock) 0.4 PJ	Case 4: Usage problem Conventional boxes in rented homes (4% of stock) 0.2 PJ

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[52] Based on 72 PJ total electricity use.

Description of the results

Approximately 68.4 PJ/year of electricity consumption is affected by an efficiency problem. This corresponds to slightly less than 1.5% of total U.S. residential electricity use in 2006. Almost 100% of the energy consumption in the set-top box end use is affected by PA problems in Cases 2, 3 and 4.

There are no policy factors mitigating the PA problem in this market. No efficiency regulations eliminate the lowest-efficiency units and no information labels or endorsement programs help consumers identify energy-conserving units.

No present market trends appear to be working towards elimination of these PA problems. ENERGY STAR recently decided to re-establish a voluntary efficiency program but it has not yet identified an approach that will overcome the lack of incentives for the service providers.

Carbon emissions trading and corporate commitments to achieve carbon neutrality may offer some new incentives. A British service provider, BSkyB, recently introduced a scheme to remotely switch its set-top boxes to standby power after periods of inactivity (BSkyB, 2007). This action will cut the typical set-top box's electricity consumption by about 13%. Similar programs have not been announced in the United States.

Potential energy savings

The set-top box is rapidly changing because new features are constantly being added. The most important additions will be incorporation of hard disks, high definition service, and multiple tuners. These new features have major implications for energy use and savings potentials. The level of service must be carefully defined when estimating energy savings. This study estimated the energy savings assuming that boxes with similar levels of service – but much more efficient – will replace the existing boxes.

In 2006, the 148 million set-top boxes in the United States were responsible for about 20 TWh/year of electricity, or about 16 watt for each box. Most boxes today have limited functionality. Service providers plan on a useful life of seven years for their boxes.

There have been no detailed investigations of energy savings potentials in set-top boxes; however, many components are similar to those personal computers and mobile telephones (where no PA problem exists). Some of the solutions found in laptop computers and mobile telephones certainly apply to set-top boxes. Major efficiency improvements are listed in Table 37.

TABLE 37

Energy-saving strategies for set-top boxes[53]

Measure	Explanation
Power management	Switch off components when not actually required, including hard disk, image processing chips, and multiple tuners
More efficient components	Install switch-mode power supply and more efficient chips for image conversion
Reduce disk energy use	Install more efficient disk designs, switch to flash memory, or store content at a remote server
Lower clock speeds on chips	Reduce processing speed to minimum speed for type of image transmitted
Consolidate boxes	Some homes use two or more boxes to provide signals to several televisions
Relax security requirements	Service provider currently restricts ability of box to enter low power modes to guard against hackers and to protect content
Allow user to set functionality	Through a control panel, the user could modify settings to more precisely match his needs, possibly resulting in even greater energy savings

Based on these technologies, a box with an average power of about 4 watts appears economically feasible. This corresponds to a 75% reduction in energy use (or 15 TWh/year). The large savings arise mostly through improved power management, which greatly reduces electricity consumption during times when the box is not actively decoding. As mentioned earlier, a European service provider was able to achieve a 13% reduction in energy use through power management. This was accomplished with little technical modification and at almost no cost.

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[53] Based on presentations at the "Workshop on Energy-Efficient Set-Top Boxes and Digital Networks" at the International Energy Agency, Paris, France, 4-6 July 2007.

Conclusion and policy recommendations

The goal is to devise policies that internalise energy costs in the design, manufacture, and operating decisions related to set-top boxes. Although the PA problem spans most of the set-top box industry, the solutions may be particular to cable, satellite, or internet networks. Some possible solutions that can help to capture the energy saving potential include:

- Require service providers to reimburse customers for the electricity costs of the set-top boxes. Service providers can easily determine the power of each model in the laboratory and accurately estimate the monthly electricity consumption. With this information and local electricity rates, the service provider can calculate the cost of a box's electricity consumption and reimburse the customer. This arrangement encourages the service provider to buy efficient boxes and to minimize periods where the box must be in an active mode for security, downloads, and maintenance. The energy reimbursement might be based on standby power consumption because this is the cost to the consumers if they never switch on the box. This approach could apply to cable, satellite, and internet networks.
- Mandate minimum efficiency standards for set-top boxes. It is possible to establish maximum levels of power consumption for set-top boxes. The European Code of Conduct (European Commission, 2007) has recommended levels based on the boxes' functionality. The technologies are evolving rapidly, however, and it is not clear if a regulation will be able to keep up with new features and functionality. An efficiency regulation minimizes the impact of PA problems but does not eliminate it.
- Include minimum efficiency requirements in cable franchise agreements. Local franchises for cable service already include many special requirements (such as free connections to government buildings and schools) so requiring minimum levels of efficiency would not be a precedent. An efficiency stipulation in the franchise agreement minimizes the impact of PA problems but does not eliminate it.
- Offer financial incentives for efficient set-top boxes. A financial incentive to manufacturers might encourage them to build more efficient boxes. However, the benefits need to flow to the service provider to achieve the best results. There is no certainty that the service providers would accept the incentive or that the energy savings would occur. A program similar to this is underway in

the United States to ensure that Digital Television Adapters (DTAs) are energy efficient. In this case, the service provider does not need to cooperate in order to achieve the energy savings but the savings will be limited to those available through efficiency improvements in the box rather than through improved coordination with the service provider.

End-use appliances: case studies

PRINCIPAL-AGENT PROBLEMS IN END-USE APPLIANCES: VENDING MACHINES

This chapter focuses on Principal-Agent problems in the vending machine end-use sector. PA problems, defined in Chapter 1, occur when economic inefficiencies arise during an economic exchange between two parties (a "principal" and an "agent") who have different goals. Case studies in Japan and Australia investigate and quantify PA problems in that country.

Before turning to the case studies, this chapter overview takes the theoretical discussion of Agency Theory applied to energy efficiency (provided in Chapter 2) one step further, by applying Agency Theory to the specific characteristics of energy efficiency in the vending machine end-use sector.

Agency Theory and energy efficiency issues in the end-use appliance sector: vending machines

Chapter 2 provides a useful summary of the specific dimensions of Agency Theory applied to energy efficiency. Using the same dimensions of Agency Theory from Chapter 2, this study applies Agency Theory to the vending machine end-use sector. A summary is presented in Table 38.

Identifying the principal and the agent in the vending machine end-use market

Transactions between principals and agents in the vending machine sector in Japan are illustrated in Figure 28.

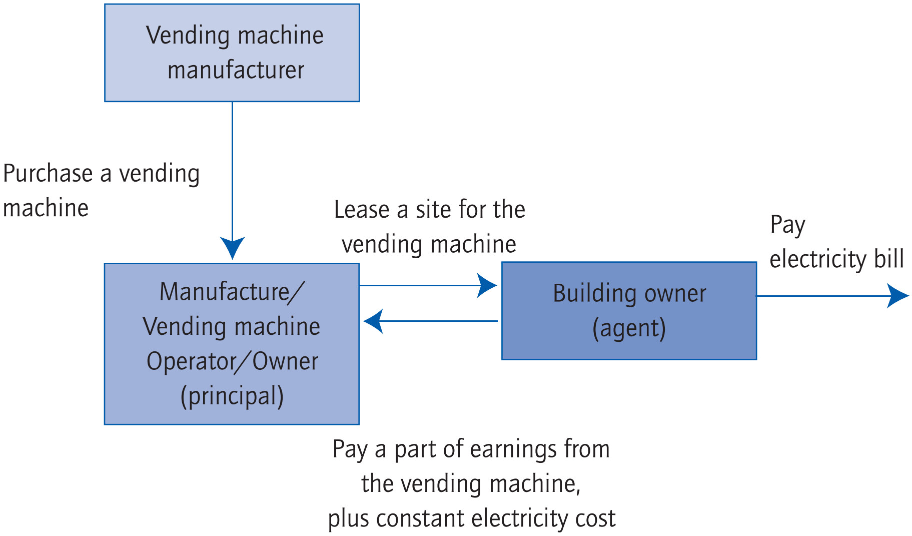
TABLE 38

Dimensions of Agency Theory applied to vending machine end-use market

Dimension	Standard application of agency theory (owner-manager)	Vending machine end-use context
Unit of analysis	Relationship (and contract) between owner (principal) and manager (agent)	Relationship (and contract) between building owner (agent) and vending machine owner (principal)
Problem domain	Relationships in which the principal and agent have different levels of information and partly differing goals	Relationships in which the principal and agent have different levels of information about energy efficiency and partly differing goals
Goal orientation of the actors	Goal conflict between principal and agent. Owner's goal is to maximise returns. Manager's goal may be to limit work levels required.	Goal conflict between principal and agent. Vending machine owner's goal is to maximise returns/minimise capital costs. Building owner's goal is to limit energy costs
Key objective	Principal-agent relationships should reflect efficient organisation of information to maximise economic efficiency	The energy user *and* energy technology provider should both consider energy costs
Human assumptions	Self-interest Bounded rationality Individual autonomy	Self-interest Bounded rationality Individual autonomy
Organisational assumptions	Partial goal conflict Economic efficiency as the criterion Information asymmetry Agent delegated the task by passive owner principal	Partial goal conflict Energy efficiency as the criterion Information asymmetry Agent provides accommodation to tenant (principal)
Assumption about the source of problem	Contract inadequate	Contract inadequate in that is set up in a way that at least one party that is involved in energy-related decisions is insulated from the energy price
Implications of inefficient relationship/contract	Adverse selection Moral hazard Split incentives	Adverse selection Moral hazard

FIGURE 28

Principal and Agent in vending machine transactions in Japan



This figure shows the financial and physical relationships among actors in the vending machine market in Japan. The beverage manufacturers and vending machine operators purchase and own beverage vending machines produced by the manufacturer. A beverage manufacturer and vending machine operator enter into a contract with a building owner (such as a grocery store or office) to rent the vending machine site. The beverage manufacturers and vending machine operators are the “principals” and the building owners are the “agents” in this transaction. In the contract, the building owner leases the vending machine site to the beverage manufacturers and vending machine operators. In exchange for the site, the building owner receives a part of earnings from the vending machine.

In Australia, two large multinational companies that import vending machines, mostly from the US, dominate the refrigerated beverage market. The company that imported the machine usually retains ownership of it. The importer enters into a rental contract with a building owner/operator (such as a supermarket, grocery store, restaurant or office), which pays the electricity bills. In this case, the vending machine importer is the principal and the building owner/operator is the agent. There are some differences with major operators and the small independent operators in the Australian market.

Identifying Principal-Agent problems in the vending machine end-use market

Identifying Principal-Agent problems in the vending machine end-use market involves searching for transactions where PA problems may be present. This requires understanding who pays the electricity bill and who chooses the equipment.

In Australia, the principal commonly selects which machines to import, and thereby determines which technology is available to the agent. According to the Miminum Energy Performance Standards (MEPS), the technology offered by the Principal is often of suboptimal efficiency. Machines are also available through other importers, which enable the operators to stock beverages of their choice. The contracts offered by major operators are usually 'total service vending' where the owner receives earnings from the sale of the beverages after operating fees are deducted. The agent pays the electricity bill.

In Japan, although the beverage manufacturers and vending machine operators do not pay the electricity bill to electric company directly, they pay more or less the same amount of the electricity cost to the building owners, in addition to the rent for the site of the vending machine. The contract formula for calculating payment to the building owner thus consists of two components: rent and electricity. In most cases, the electricity component is constant, calculated on an assumption basis considering specifications of the vending machine, not on an actual basis using metered electricity cost.

Display cabinets, a different kind of vending machine, are also used in Japan. In most cases, building owners purchase the remote condensing display cabinets and pay the electricity bill. Building owners therefore have the incentive to take future energy costs into consideration when choosing the energy efficiency level of the display cabinet. This indicates that there is Principal-Agent problem in the remote condensing display cabinet market in Japan.

Some building owners purchase plug-in display cabinets, and pay the electricity bills. However, in other cases, beverage manufacturers purchase plug-in display cabinets and provide them to building owners at no expense. They close a contract by purchasing soft drinks or beers from the beverage manufacturers, and the building owner pays the electricity bills. In the latter case, the beverage manufacturer has no incentive to consider the future energy costs of the display cabinet because they do not bear the electricity cost. This indicates that a split-incentive, or Principal-Agent Problem might be present in the plug-in display cabinet market.

PA problems in the vending machine market can be categorised into the four cases discussed in Chapter 2, depending on who bears the responsibility for paying the energy bill and who makes decisions on energy saving measures. Each case study presents the four cases in greater detail.

If the person paying the energy bill is not the person using the technology, the user may consume more energy than if he were not shielded from the price of energy. This is referred to as a usage problem. Similarly, if the person paying for the energy is not the person choosing the technology, the technology buyer will generally choose among the cheapest, and often least efficient, options. This is referred to as an efficiency problem.

A CASE STUDY ON PRINCIPAL-AGENT PROBLEMS FOR JAPANESE VENDING MACHINES AND DISPLAY CABINETS

This case study quantifies the potential size of Principal-Agent problems in the vending machine and display cabinet sectors in Japan.

Energy use in the Japanese vending machine and display cabinet sector and energy efficiency policies

Energy use in the Japanese vending machine and display cabinet sector

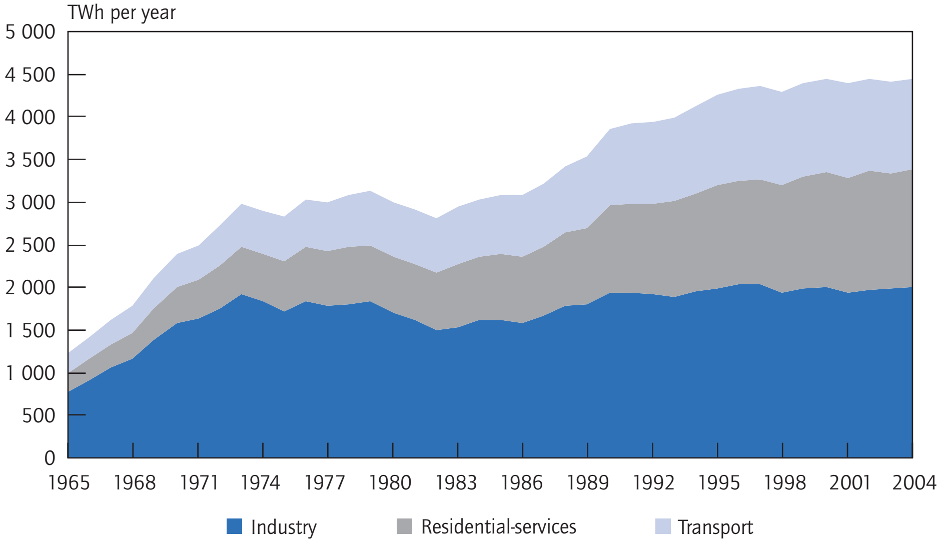
In Japan prior to the 1970s, energy consumption growth outstripped the rise of GDP. However, the oil crisis of the 1970s as well as the historic dependence of the country on foreign energy, accelerated the development of energy-efficient products and energy efficiency improvement efforts in the industrial sector. After the 1980s, energy consumption once again increased due to relatively low oil prices and lifestyle changes, including desires for greater comfort.

In 2004, the residential and service sectors accounted for about 30% of total energy consumption as shown in Figure 29. Energy consumption in the residential-service sector increased by 35% between 1990-2002 to reach approximately 5 PJ per year. This growth was higher than in the industry and transport sectors, which was 13% and 20% respectively for the same period.

Figure 30 shows CO_2 emissions from each sector from 1990-2004. The figure shows that CO_2 emissions from industry and transportation sectors have decreased or the margin of increase during this period is small. On the other hand, the energy consumption of the residential and service sector has grown by 32% and 38% respectively during the same period (Ministry of Economy Trade and Industry, 2006). There is room for improvement in the implementation of energy-saving measures in the residential and service sector.

FIGURE 29

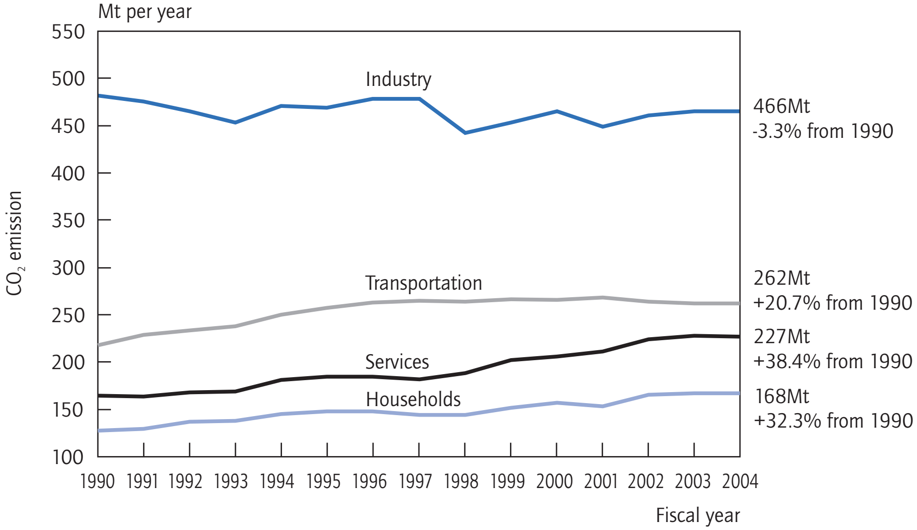
Final energy demand for each sector in Japan



Source: Energy White Paper, 2006; Ministry of Economy Trade and Industry, 2006.

FIGURE 30

CO_2 emissions from each sector in Japan



Source: Greenhouse Gas Inventory Office of Japan.

Japan uses the second largest number of vending machines in the world. In 2006, Japan used 5.5 million units in 2006, second to the US that has the largest number, 7.8 million units. The EU follows the US and Japan as the third-largest user of vending machines, with 4.0 million units (Japan Vending Machine Manufacturers Association, 2007).

This case study focuses only on beverage vending machines for several reasons. First, they require chilling and heating. Second, they occupy the largest share, 47%, of the number of machines operated. Third, they use large amounts of electricity – about 17.2 PJ annually. This is approximately equal to half of the annually generated electricity by a latest 1 350 000 kW-class (equivalent to 1.35 GW-class) nuclear power plant. It is this large-scale electricity consumption that makes it important to consider PA problems in this sector.

Energy efficiency policies

In order to diffuse appliances that are highly energy efficient, the Energy Conservation Law makes it obligatory for manufacturers and importers to ensure their products meet energy-saving target standards. The Japanese government launched the Top Runner Programme based on the amended Law in 1999, under which the standards are set based on the efficiency level of the most efficient product commercially available in a given category. For each manufacturer and importer, the Top Runner Programme requires the weighted average efficiency of all units shipped within the same category meets the standards for that category by the target year decided for each category. Target products of the Top Runner Programme include designated machinery and equipment that are commercially used in large quantities in Japan, consume significant amounts of energy when in use and where the scope and social demand to improve energy consumption efficiency currently exists.

Both the coverage of the Programme and entry years of each product into the Programme is indicated in Table 39.

The Top Runner Standard is different from Minimum Energy Performance Standards (MEPS). The measurement method primarily uses Japan Industrial Standards (JIS). The energy efficiency of the device is listed in catalogues and

Table 39

Entry year of products into the Top Runner Programme

Passenger vehicles Air conditioners Fluorescent lights TV sets Video casset recorders Copying machines Computers Magnetic disk units Freight vehicles Electric refrigerators Electric freezers	Space heaters Gas cooking appliances Gas waters heaters Oil water heaters Electric toilet seats Vending machines Transformers (molded)
11 products above were designated originally in 1999	**Additional 7 products above were designated in 2002**
LPG passenger vehicles were added to the category of a passenger vehicle in 2003	Microwave oven Electric rice cooker DVD Recorder Additional 3 products above were designated in 2006 Total 21 products are designated as of July 2006

Source: *Japan Energy Conservation Handbook 2004/2005*; The Energy Conservation Center, Japan, 2005.

on the device itself. Target compliance years are set considering future technological development forecasts and a product's development period, usually in the range of four to eight years from the base fiscal year, as shown in Table 40.

Beverage vending machines were added to the Top Runner Programme in 2002. They were added because they use relatively large amounts of electricity compared to other energy-consuming equipment. Improvement of equipment energy efficiency is strongly required. Under the Top Runner regulation, by a target year of 2005, beverage vending machine manufacturers were required to make an approximate 34% additional reduction in per machine electricity use compared to the 2000 level. The incoming Top Runner energy-efficiency standard for vending machines is now under discussion by a governmental sub-committee for judgement criteria for vending machines.

TABLE 40

Target fiscal year and effects of Top Runner Programme

	Equipment	Target fiscal year	Expected energy Conservation effects as of the previous fiscal year of the target
1	Gasoline passenger vehicles	FY 2010	Approx. 23% compared to FY 1995
	Diesel passenger vehicles	FY 2005	Approx. 15% compared to FY 1995
	LPG passenger vehicles	FY 2010	Approx. 11.4% compared to FY 2001
2	Air conditioners	Frozen at FY 2007 Frozen at FY 2004: Frozen at FY 2004 for blower/wall type items for cooling/heating under 4kW	Approx. 63% compared to FY 1997 for coolers/heaters; approx. 14% for dedicated cooler
3	Fluorescent lights	FY 2005	Approx. 16.6% compared to FY 1997
4	TV sets	FY 2003	Approx. 16.4% compared to FY 1997
5	Video cassette recorders	FY 2003	Approx. 58.7% compared to FY 1997
6	Copying machines	FY 2006	Approx. 30% compared to FY 1997
7	Computers	FY 2005	Approx. 83% compared to FY 1997
8	Magnetic disk units	FY 2005	Approx. 78% compared to FY 1997
9	Diesel freight vehicles	FY 2005	Approx. 7% compared to FY 1995
	Gasoline freight vehicles	FY 2010	Approx. 13% compared to FY 1995
10	Electric refrigerators & freezers	FY 2004	Approx 30% compared to FY 1998
11		FY 2005	
12	Space heaters	FY 2006	Approx. 1.4% compared to FY 2000 for gas space heaters, approx. 3.8% for oil space heaters
13	Gas cooking appliances	FY 2006	Approx. 13.9% compared to FY 2000
14	Gas water heaters	FY 2006	Approx. 4.1% compared to FY 2000
15	Oil water heaters	FY 2006	Approx. 3.5% compared to FY 2000
16	Electric toilet seats	FY 2006	Approx. 10% compared to FY 2000
17	Vending machines	FY 2005	Approx. 33.9% compared to FY 2000
18	Transformers	FY 2006: oil-filled transformers FY 2007:mold transformers	Approx. 30.3% compared to FY 1999
19	Microwave oven	FY 2008	Approx. 8.5% compared to FY 2004
20	Electric rice cooker	FY 2008	Approx. 11.1% compared to FY 2003
21	DVD recorder	FY 2008	Approx. 22.4% compared to FY 2004

Source: *Japan Energy Conservation Handbook 2004/2005*; The Energy Conservation Center, Japan, 2005.

Moreover, Japanese law makes beverage manufacturers and vending machine operators indirectly responsible for paying the electricity bill of the vending machine. Although the building owner pays the electricity bill of the vending machine to the electric company, the beverage manufacturers and vending machine operators pay the electricity bill indirectly because the contract includes an electricity component in addition to the rent component.

In most cases, the electricity component is constant, based on a calculation that considers the specifications of the vending machine, not on an actual basis using metered electricity cost. Although there could be a difference between the electricity component in the contract and the actual bill payment, the beverage manufacturer and vending machine operator are deemed to compensate the electricity cost of the building owner. The electricity component is expected to decrease as the vending machine's energy efficiency level improves due to stricter Top-Runner programme regulations.

Energy challenges in the Japanese vending machine and display cabinet sector

Vending machines

Vending machines are coin-operated machines that automatically provide a wide variety of goods including soft drinks, cigarettes, candy, newspapers and tickets. Vending machines can be seen almost everywhere in Japan, not only inside buildings including factories, universities, hotels, railroad stations and offices, but also in road-side rest areas. Vending machines are part of everyday life in Japan. Figure 31 shows an example of a vending machine installed at a roadside rest area in Japan.

Beverage vending machines for cold and hot beverages are widely used in Japan. They chill canned or bottled beverages during the summer. They chill some beverages and at the same time warm other beverages during winter.

Approximately 62% of the beverage vending machine's electricity consumption is used for heating, 22% for cooling, 10% for lighting and 6% for others respectively. Therefore, more electricity is consumed during winter than during summer (JVMA).

FIGURE 31

Example of a vending machine installation in Japan

Vending machines, which are usually installed in office buildings and on roadsides in Japan, consume a substantial amount of electricity. Actors in the vending machine business include vending machine manufacturers, beverage manufacturers, vending machine operators and building owners.

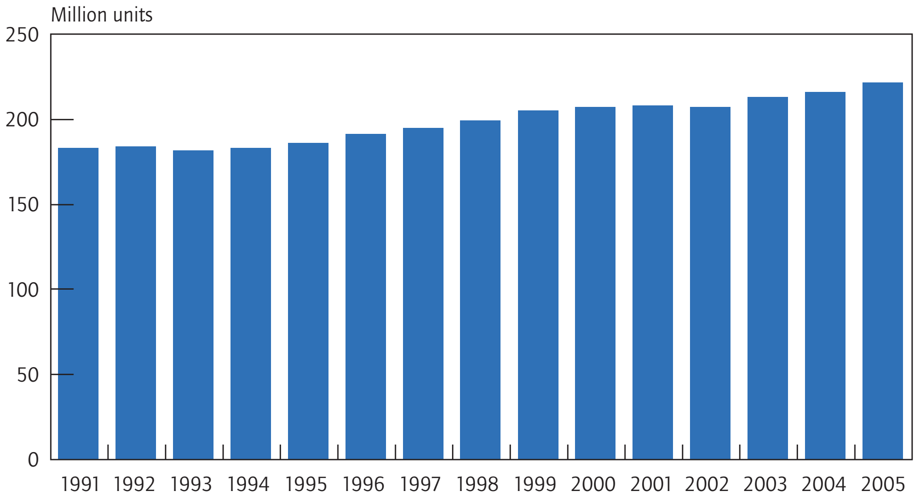
The common arrangement is for beverage manufacturers to rent a space for their vending machines from a building owner. The building owner chooses a combination of drinks to maximize earnings. Vending machines are usually installed in the building, and the building owners usually pay the electricity bills. As discussed in the energy efficiency policies section, the beverage manufacturer or vending machine operator compensates the building owner for the electricity costs via a contractual provision. The beverage manufacturer or vending machine operator selects the vending machine.

In the 1990s, the Japanese vending machine industry began to work voluntarily on beverage vending machine energy efficiency. Moreover, in co-operation with electric power companies, the vending machine industry developed and diffused ‘eco-vendor’ canned drink vending machines to reduce peak electricity demand during summer peak hours 13:00 to 16:00 on summer weekdays. These machines pre-chill beverages in cans or bottles prior to peak-demand hours. These activities resulted in a 33% reduction in the per machine electricity use of beverage vending machines shipped to the domestic market in 2001 compared to 1991 levels.

Figure 32 shows the number of beverage vending machines operated in each year. The number of beverage vending machines operated has increased by 21% from 1991-2005.

FIGURE 32

Number of beverage vending machines operated each year from 1991-2005, Japan



Source: Japan Vending Machine Manufacturers Association, 2007.

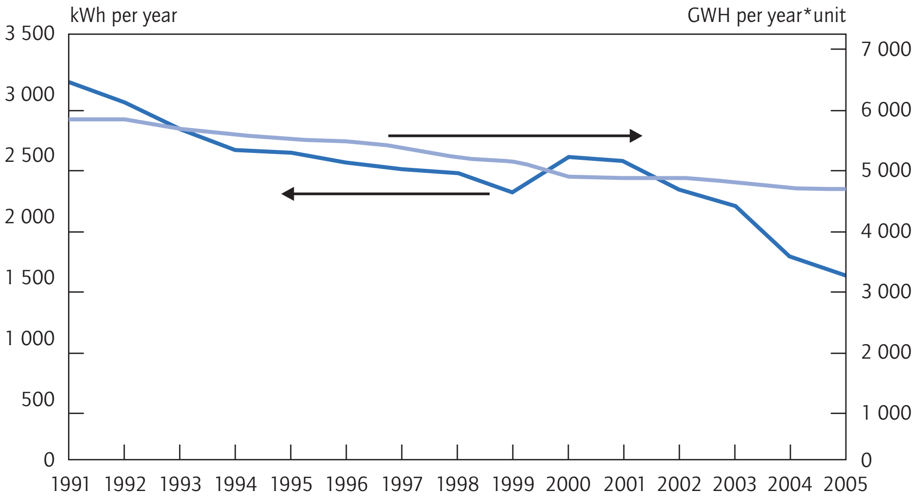
In Figure 33, the solid curve represents the per unit electricity consumption of beverage vending machines shipped in each year in kWh/yr. The dotted curve represents total electricity consumption of all beverage vending machines operated in Japan in kWh/yr. The overall electricity consumption of vending machines has decreased in the past decade, with an increase in the number of installed machines during the same period.

The electricity consumption of individual machines had decreased until 2000 and then increased. This was caused by the revision of test methods. Until then, electricity consumption had been measured for machines representing each size of vending machines. However, the discrepancy between test results and actual electricity consumption had grown. In 2000, the test methods were revised to test all types of machines to reflect actual electricity consumption more precisely.

The voluntary efforts of the vending machine industry were a major contributor to reducing vending machine electricity consumption from 1991-2000. Improvements in energy efficiency have been more rapid since 2002, when the Top Runner programme began covering vending machines.

FIGURE 33

Electricity consumption of beverage vending machines operated in each year from 1991-2005, Japan[54]



Source: Japan Vending Machine Manufacturers Association, 2007.

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[54] Note that the apparent increase from 1999-2000 is due to the change in testing method.

Display cabinets

Display cabinets are machines that chill bottled or canned drinks, perishable foods and frozen foods. They are used mainly in supermarkets, grocery stores and convenience stores for displaying items for sale. Figure 34 shows an example of a display cabinet in Japan.

A shopper can open the door of the display cabinet and pick items freely from the inside to buy. There are two types of display cabinets, a plug-in and a remote condensing type. The former has a refrigerating unit inside the machine and the latter has multi-display units placed inside the building and a single separate condensing unit placed outside the building. About 0.3 million display cabinets were shipped to the domestic market in 2004 (see Figure 35). Two-thirds were the plug-in type and one-third were the remote condensing type. There are approximately 4.0 million display cabinets operated in Japan at present, assuming that the display cabinets have an average actual life time of ten years (The Japan Refrigeration and Air Conditioning Industry Association, 2007).

Display cabinets installed at supermarkets and convenience stores for storing and displaying foods and beverage are widespread in Japan. Electricity consumed by these machines is likely to be large. There are likely to be Principal-Agent problems in this sector as well, given the complex roles actors play in this sector in Japan.

Presently, the Top Runner programme does not cover display cabinets. However, manufacturers have made voluntary efforts to improve energy efficiency to respond to rising public awareness of the environment.

The size of Principal-Agent problems

Data collection

PA problems in the vending machine sector focus on the inefficiencies of energy use that arise when the person choosing the technology is not paying the energy bill. The overview section to this chapter elaborates further on these PA problems. The purpose of this section is to examine the size of PA problems in the Japanese vending machine and display cabinet markets.[55] The calculation is

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[55] This study does not investigate in detail the potential Principal-Agent problems associated with the purchase of vending machines by beverage manufacturers.

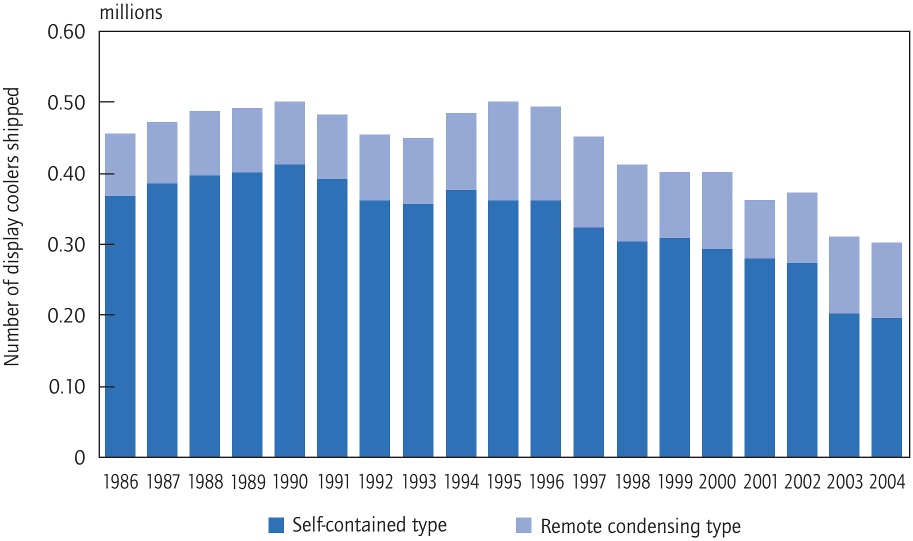
Figure 34

Example of a display cabinet in Japan

Source: Fukushima Industries Corp.

Figure 35

Number of display cabinets shipped to domestic market



Source: The Japan Refrigeration and Air Conditioning Industry Association, 2007.

a simple multiplication of three components: 1) the number of machines operated; 2) per machine annual energy use; and 3) the fraction of the machines affected by PA problems described above. The multiplication shown below gives the total nation-wide energy use affected by PA problems for each type of equipment.

$$E(\text{affected}) = N \times EE \times P \qquad \textbf{Equation 1}$$

Where:

E(affected) is the energy use affected by market barriers (in kWh/yr)

N is the number of machines operated (units)

EE is the electricity use per machine (kWh/yr/unit)

P is the proportion of machines affected by market barriers (%)

Description of the results

Vending machines

There are approximately 2.6 million beverage vending machines operated in Japan at present (Japan Vending Machine Manufacturers Association, 2007), consisting of 2.2 million for soft drinks, 0.18 million for milk, 0.16 million for coffee and 0.05 million for beer and other alcohol. JVMA estimates the per machine electricity use to be 5.7 GJ/yr/unit at present. This case study assumes the fraction affected by PA problems is zero. This assumption is based on considering the financial and physical relationships among the actors which is discussed in more detail below and summarised in Chapter 2 and in Table 41and Table 42. Based on these figures, this case study estimates the electricity use affected by PA problems is simply zero.

Display cabinets

There are approximately 4.0 million display cabinets operated in Japan at present. They consist of 1.1 million of the remote condensing type that are not affected by PA problems and 2.9 million of the plug-in type, part of which might be affected by PA problems. This case study concludes that there is no split-incentive problem in the remote condensing type display cabinet market and the fraction of remote condensing-type display cabinets affected by PA problems is zero. This is based on the consideration of financial and physical relationships among the actors as shown in Figure 36.

Among 2.9 million of the plug-in type display cabinets, 0.96 million are free beverage display cabinets, and 1.94 million are other display cabinets that are purchased by the end users. Based on the consideration of financial and physical relationships among the actors as described in more detail below, this case study assumed approximately 33% of the plug-in type display cabinets are affected by the split-incentive problem.

Electricity consumption of display cabinets in Japan potentially affected by PA problems is calculated using Equation 1 as shown in the equation below (Equation 2). The first term of the equation represents the electricity use of remote condensing type display cabinets affected by PA problems. This is zero since this case study assumes that the fraction affected by PA problems is zero. The second term represents the electricity use of the plug-in type display cabinets. Per machine electricity use is estimated to be 6.5 GJ/yr/machine based on results from a measurement survey of display cabinet electricity use conducted by CRIEPI. The electricity use of remote condensing type display cabinets affected by PA problems is calculated to be 6.1 PJ/yr.

$$\begin{aligned} Elec(affected) &= (1.1 \text{ million} \times 1\,800 \times 0) + (2.9 \text{ million} \times 1\,800 \times 0.33) \\ &= 1\,722\,600\,000 \text{ kWh/yr} \end{aligned} \qquad \textbf{Equation 2}$$

Where:

Elec(affected) is the electricity consumption (in kWh/yr) of display cabinets in Japan potentially affected by PA problems.

Discussion of possible split incentives and Principal-Agent problems in the Japanese beverage vending machine market

TABLE 41

Principal-Agent classification of beverage manufacturers and vending machine operators*

	End user chooses technology	End user does not choose technology
End user pays the energy bill	Almost 100%	0%
End user does not pay the energy bill	Negligible	0%

* Beverage manufacturers and vending machine operators pay more or less the same amount of electricity cost to building owner.

TABLE 42

Principal-Agent classification of building owners

	End user chooses technology	End user does not choose technology
End user pays the energy bill	0%	Negligible
End user does not pay the energy bill	0%	Almost 100% (compensated by beverage manufacturers or vending machine operators)

As explained above, the beverage manufacturers and vending machine operators invest in the energy efficiency of the vending machine and bear the electricity costs. This implies that there are no split incentive problems in the Japanese vending machine market.

Improvements in the energy efficiency of the vending machine bring increasing profits to the beverage manufacturers and vending machine operators through a reduction of the electricity cost.

Since beverage vending machines are generally replaced every seven to eight years (Japan Vending Machine Manufacturers Association, 2007), energy efficiency technologies with a payback time of less than seven to eight years are possibly employed.

Discussion of possible split incentives and Principal-Agent problems in the Japanese display cabinet market

Two types of display cabinets are presently used in Japan, remote condensing type and plug-in type.

In most cases, the remote condensing type display cabinets are purchased and owned by building owners, and building owners pay the electricity bills. This indicates that there is no split-incentive problem in this type display cabinet market.

In the plug-in type display cabinet market, about two thirds of cabinets are purchased by building owners who pay electricity bills. Other coolers are purchased by beverage manufacturers and are provided to building owners at no expense. The building owner closes a contract by purchasing soft drinks or beers from the beverage manufacturers, and the building owner, not the beverage manufacturer, pays the electricity bills. This indicates a possible split-incentive problem in the plug-in display cabinet market.

Figure 36 shows this financial and physical relationship among actors in the market of Japanese plug-in display cabinets that are installed at convenience stores.

FIGURE 36

Financial and physical relationship among actors in Japanese display cabinet market, plug-in type

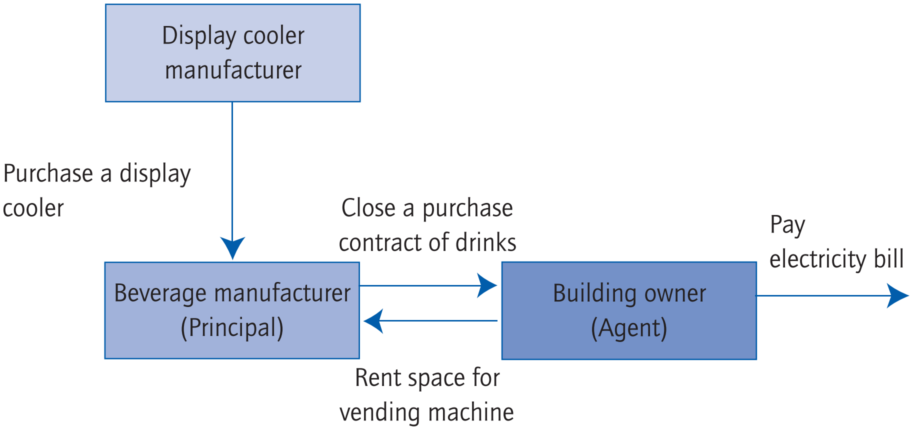


Table 43 shows the Principal-Agent classification of remote condensing type display cabinet users.

TABLE 43

Principal-Agent classification of remote condensing type display cabinet users

	End user chooses technology	End user does not choose technology
End user pays the energy bill	Almost 100%	Negligible
End user does not pay the energy bill	0%	0%

Table 44 summarizes the Principal-Agent classification of plug-in type display cabinet users. Of the annual shipment volume of plug-in type display cabinets, 60 thousand are shipped as beer displaying free display cabinets and 48 thousand are shipped as soft drink displaying display cabinets. The Central Research Institute of Electric Power Industry (CRIEPI) estimated these figures based on interview results with JRAIA. Assuming that the display cabinets have an actual life time of ten years on average, there are 0.96 million of free display cabinets running at present, with a 33% share in the plug-in type display cabinet of 2.9 million.

TABLE 44

Principal-Agent classification of plug-in type display cabinet users

	End user chooses technology	End user does not choose technology
End user pays the energy bill	67%	33%
End user does not pay the energy bill	0%	0%

Analysis and implications

In Japan, regulations make beverage manufacturers, who are responsible for the selection of machines to be shipped, pay the electricity bills. As such, vending machines in Japan are not influenced by PA problems. As for the display cabinets, 100% of remote condensing type display cabinets and 66% of plug-in display cabinets are selected by building owners who pay electricity bills. This means that the remaining 33% of 2.9 million plug-in display cabinets are likely to be affected by PA problems. As a result, the beverage manufacturer and vending machine have incentives to take future energy cost into consideration when choosing technologies of vending machine, implying that there are no split incentive problems in Japanese vending machine market.

Conclusions and recommendations

This case study illustrates that adequate policy mix can overcome PA problems. The combination of a regulatory mechanism (the Top Runner Programme) and a market transformation instrument (changing the nature of the contract between the principal and the agent) has helped overcome the PA problems.

The difference in result between the two cases – vending machine and display cabinets – is here rather telling of the impact that the policies have had on overcoming the PA problems. While the electricity consumption of vending machines, has decreased significantly over the past decades. The energy efficiency improved 33.9% between 2000-05, while that of display cabinets has not. One reason for this improvement is the voluntary efforts by the manufacturers to reduce electricity consumption. Another reason is the Top Runner Programme's strict regulation of the minimum energy efficiency of vending machines during this period. Some portion of the energy efficiency improvement could be attributed to contracts where beverage manufacturers and vending machine operators, who are substantial end-users, also pay the electricity bills.

By making the beverage distributor responsible for both choosing the machine and paying the electricity bill, the contract implicitly gets rid of the agent, creating a Case 1, rather than a Case 2-4, situation. The imposition of the strict minimum energy efficiency standards of the Top Runner programme ensured that beverage distributors chose energy-efficient vending machines. Results show that vending machine's electricity consumption significantly decreased once the Top Runner Programme entered the market. This suggests that the mandatory energy efficiency standards were indeed effective.

The role that falls to government in such contract design is difficult to determine. The rules of a private transaction in a liberalised market should be left to the individual parties to decide. However, the market failure which characterises the majority of these transactions warrants government intervention to design a template that aligns responsibilities in the same hands. Further discussion on the nature of the government's role will be provided in the policy recommendation chapter.

Energy-savings potentials

In the Japanese vending machine and display cabinet market, 0.96 million units of display cabinets, which account for 33% of installed plug-in display cabinets, are likely to be affected by PA problems. Electricity consumption by these display cabinets in Japan is estimated to be 6.1 PJ/yr. This is about one sixth of the electricity generated by a latest 0.0048 PJ-class nuclear power station in a year.

VENDING MACHINE ENERGY USE IN AUSTRALIA AFFECTED BY PRINCIPAL-AGENT PROBLEMS

The purpose of this case study is to examine the role of players in the Australian vending machine market, to characterize any potential Principal-Agent (PA) problems and to consider measures to overcome potential PA problems.

Energy use in the Australian vending machine market and energy efficiency policies

There is a range of vending machines in the Australian market. These include machines that vend frozen or chilled food, cold beverages, both cold beverages and snacks; non-refrigerated snacks; hot beverages from non-refrigerated machines, and hot and cold beverages and snacks (National Appliance and Equipment Energy Efficiency Program, 2005).

Overall, 'traditional' vendors dominate the Australian market. These are brand name companies with fleets of branded machines. These companies usually own the machines and often provide 'total service vending', which includes installation, servicing, and restocking with their own product lines.

Table 45 shows the estimated annual sales and installed stock of the main types of refrigerated beverage vending machines (RBVMs) in Australia.

There was a temporary increase in the import of vending machines in 2000 to cater to the influx of tourists for the Sydney Olympics.

Because there was no obvious uptake of available improved technologies and growth was predicted for RBVMs in Australia, the National Appliance and Equipment Energy Efficiency Committee (NAEEEC) published a technical report in 2004 that analysed the potential for minimum energy performance standards (MEPS) for RBVMs. In parallel, under the auspices of Standards Australia, a draft test method, based upon ASHRAE 32.1 2005, and MEPS levels were developed and published for public comment in April 2006. The next phase includes the

TABLE 45

Turnover and stocks of RBVMs in Australia by machine type (2004)

Vendor Type	Estimated annual sales	Estimated installed stock
Refrigerated beverage	1 500-2 000	100 000-120 000
Chilled snack	1 000-1 300	25 000-30 000
Refrigerated combination beverage/snack	1 000-1 300	5 000
Refrigerated food	200-300	6 000
Total	**3 700-4 900**	**148 500-161 000**

Source: NAEEEP, 2004, quoting unnamed industry source estimates.

preparation of a Regulatory Impact Statement to assess the costs, benefits and impacts of a range of options, including mandatory MEPS, voluntary MEPS, labeling and certification.

Energy use in the Australian vending machine market

In 2004 there were approximately 110 000 RBVMs in Australia that consumed approximately 520 GWh of electricity. Because the market for RBVMs is increasing, the annual energy consumption is projected to increase to 716 GWh by 2020 without intervention. However, more efficient motors, lighting and fans, together with technology to automatically power down machines when they are not in regular use, are capable of reducing energy consumption by nearly 50%. Although these technologies are available in commercially produced RBVMs in the United States, they have not been introduced into the Australian market.

The Australian Bureau of Statistics collates data on vending machine imports, but the data does not distinguish between vending machines used for refrigeration and those used for heating.

Some industry sources perceive a trend in increased sales of combined hot-and-cold beverage and snack machines. Others within the industry, however, point to problems that will limit the market penetration of combined hot-and-cold beverage and snack machines, including their higher initial cost, more labour-intensive stocking requirements, and more complicated technology that results in higher maintenance costs (National Appliance and Equipment Energy Efficiency Program, 2005).

There is also a small market for second hand and refurbished machines that have simple designs and long lifetimes According to the MEPS report, some second hand machines have been imported from Japan and have inferior energy performance.

Australia uses data based on RBVM testing and Canadian energy consumption data for models similar to those used in Australia. Table 46 provides a breakdown of energy consumption data by type of machine and percentage of the market. Total energy consumption of all types of RBVMs in Australia is estimated to be 691.4 GWh per year. For machines selling only refrigerated beverages, energy consumption is estimated to be 520 GWh per year.

TABLE 46

Estimated energy consumption by vendor type in Australia

Vendor Type	Estimated installed Australian Stocks	Daily Energy Use (from Canadian Std) *kWh*	Annual Energy Use *Gwh pa*	Percentage of Total Energy Consumption
Refrigerated beverage	110	13	5 220	75%
Chilled snack	27.5	12.3	123.5	18%
Refrigerated combination beverage/snack	5 000	7.5	14.6	2%
Refrigerated food (includes hot foods stored & cold frozen)	6 000	14.3	31.3	5%
Total consumption	**691.4 GWh pa**			

Source: NAEEP, 2005.[55]

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[55] This consumption data is derived from a static test that does not account for the dispensing or restocking of products. The report, however, concludes that the static state does indeed represent the majority of total energy consumed, although ambient temperature is also “likely to be highly influential on the total energy consumed by a unit in use”. In addition, some Australian machines may not qualify for the US Department of Energy (DOE) and Environmental Protection Agency (EPA) ENERGY STAR label, because they are fitted with inefficient T12 lamps and magnetic ballasts since Australian MEPS for fluorescent lighting were not effective until March 2003.

A report to the California Energy Commission includes various measures that can provide energy savings in vending machines. Motion-sensor activated controls and high efficiency evaporator fan/motor systems can provide the most significant savings (47% and 21%, respectively). Another report for the Australian Centre for Renewable Energy identified market barriers to improved RBVM efficiency. The report noted that although most machines could be inexpensively retrofitted to use 50% less energy and switch to environmentally preferable hydrocarbon refrigerant, "there may be little incentive for vending machine manufacturers to achieve this performance, given that the beverage manufacturers who purchase these vending machines do not pay their running costs" (Greene and Pears, 2003).

Energy efficiency policies

Australia implemented two important measures to improve the energy efficiency of appliances and equipment: The Energy Rating Label and Minimum Energy Performance Standard (MEPS).

The first Energy Rating Label was introduced in New South Wales and Victoria in December 1986 for domestic refrigerators and freezers. In 1992, the label became mandatory and its applicability extended to more products including dishwashers, clothes washers and dryers, water heaters and room air conditioners. The label indicates the product's energy consumption rates the product's energy efficiency with stars on a scale from 1 to 6. This allows consumers to compare the energy efficiency of different appliances and gives manufacturers an incentive to improve their products' efficiency and performance.[57] The label is effective: it is recognized nationwide as a credible and reliable source of information. Nonetheless, energy labeling can have little impact on consumer decisions if an intermediary or the person not paying the electricity purchases the appliance.

The energy labeling system did not eliminate the least efficient products from the market. As a result, the government implemented MEPS for residential appliances and commercial and industrial equipment. MEPS sets minimum standards that must be met before the products can be sold. MEPS first applied to domestic refrigerators and freezers in October 1999. MEPS applied to commercial

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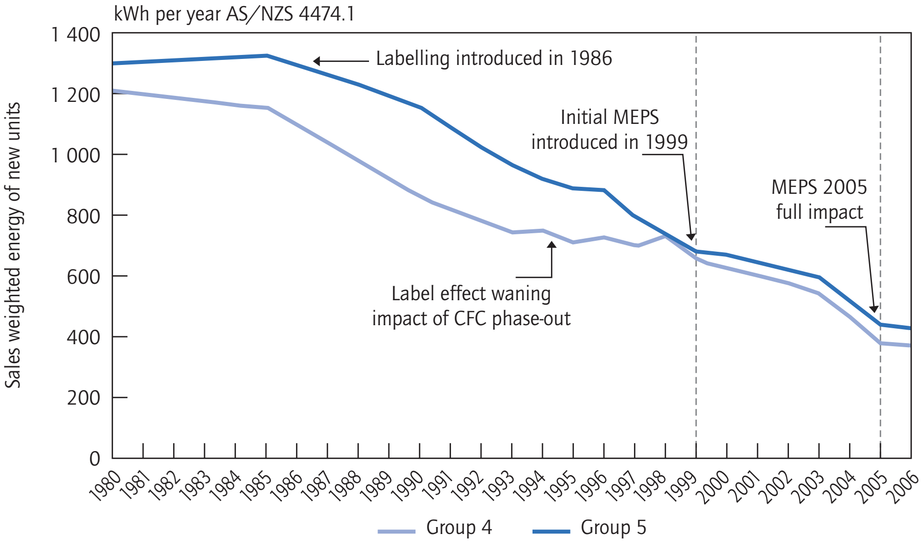
[57] A survey conducted for the Equipment Energy Efficiency Committee in 2005 found that 75% of consumers consider the energy rating label an important factor in the appliance purchasing process and they consult the label for cost and energy saving information.

refrigerators beginning in October 2004 as Australian Standard AS 1713.14-2003. These requirements do not yet apply to vending machines but they are being considered in the MEPS Regulatory Impact Statement. The planned programme for RBVMs is to match standards used by the United States EPA. Previous MEPS have been effective in improving average efficiency of appliances, therefore it is expected that there will be no difference for RBVMs.

From 1980 to the introduction of MEPS in 1999, the energy consumption of refrigerators and freezers decreased by approximately 50%. From 1999-2005, their energy consumption decreased further by 40%, resulting in an overall reduction of up to 70% from 1980-2005 (see Figure 37). Energy efficiency[58] increased by 4.6% per year over the period.

FIGURE 37

Energy consumption trends in Australia: new refrigerator-freezers (1980-2006)



Note: Group 5 (frost-free) energy trends from 1993 are for top-mounted models only.
Source: *Matching World's Best Regulated Efficiency Standards – Australia's success in adopting new refrigerator MEPS* (Harrington and Holt, 2002).

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[58] Considering volume changes.

The size of Principal-Agent problems

Data collection

This study estimates that 20% of the RBVM market is comprised of small operators using second hand machines. This study assumed the remainder is large operators falling into Case 2. The total estimated proportion of the market affected by PA problems is therefore 80%. This study used 2004 figures from the MEPS report, which cites the total energy consumption of the 110 000 RBVMs in Australia at 520 GWh of electricity per year, to estimate the energy affected by PA problems at 80% of 520 GWh, or 416 GWh of electricity per year.

Energy savings could be achieved by implementing the voluntary ENERGY STAR levels that California will be mandating. This could potentially result in 7.2 GJ per year in energy savings. Running a more efficient machine could yield savings to the operator of AUD 180 per machine per year, with a payback of 0.74 years. Adopting more efficient lighting and motion-sensor activated controls (lighting typically comprises 40% of running costs for machines fitted with promotional lighting) could potentially achieve additional savings.

There are a number of independent vending operators who supply machines at no cost to the agent. The agent pays the electricity costs but the Principal retains all earnings from sales (or sometimes 90% of profits) This is commonly the case in sports clubs and offices, where service is most important. It has proved extremely difficult to quantify this part of the market, which appears to fall under Case 2. Again, there is a choice of machines, but decisions on which machine to choose tend to be made based on product range. None of the independent vendors contacted could provide details on the energy use of the available machines. Collins (personal communication to the author) suggested purchasers in this part of the market buy from other importers so they can offer machines that can be stocked at the operators' choice.

There is no easily verifiable data available to determine the influence of minor players in the market. However, it is apparent that the few major market operators dominate the decisions on machine selection. By inference, this affects the energy efficiency of the vending machines used in Australia. These market conditions are illustrated by the fact that in 2003 the Australian Competition and Consumer Commission opposed a major beverage company's proposed acquisition of a major fruit juice company because of the potential for that company to dominate all aspects of the beverage market, including the vending machine segment.

While the majority of the RBVM market in Australia conforms to Case 2, a small segment of the market (~20%) consists of agents who purchase second hand machines or machines that are not supplied by beverage companies. Thus the agent chooses the technology, (although the machines are usually inefficient and there is little real choice or information on which to base a choice) and pays the bills, conforming to Case 1. The operator/agent would probably not have a major concern with energy use because it represents a comparatively small cost. However, the operator would be sensitive to the difference between the purchase and sale price for "used" machines.

Description of the results

This case study uses data from the MEPS publication, which relies on the following sources and limitations:

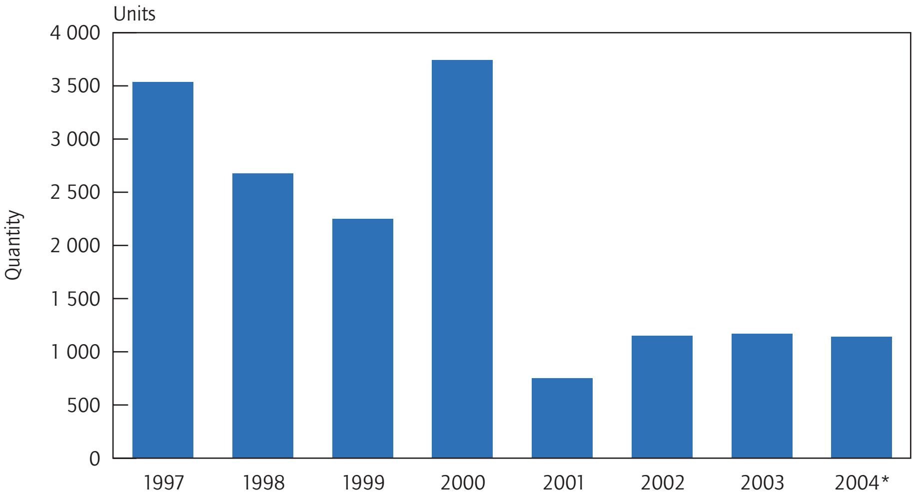
- import figures used in Table 45 are based on unspecified industry sources, in an industry dominated by a few major operators;
- energy consumption figures are based on Canadian standards for the performance of RBVMs and tests conducted on models used in Australia;
- there is a lack of data from small independent vendors; and
- no data could be found on the effects of MEPS for lighting (introduced in 2003) on the energy efficiency of RBVMs.

The surge of new machine imports just prior to the Sydney Olympics and a consequent reduction since 2001 (see Figure 38) have influenced the data. This may effectively reduce the rate of introduction of newer more energy-efficient machines.

The ongoing liberalisation of the national energy market in Australia will introduce price differentials according to time of day demands. The goal of this policy is to reduce peak demand to minimise the need to build additional power stations and upgrade the associated infrastructure. Smart meters or 'interval price meters' are also progressively being introduced to provide better information to consumers on energy costs in association with the changes in the energy market. This may increase the awareness of the 'agents' to energy costs as the 'time of use' charges are implemented and agents analyse their bills.

FIGURE 38

US imports by year: refrigerated/heated beverage machines



* 2004 data extrapolated from Oct. 2004.
Source: NAEEP, 2005.

Coca Cola Amatil has recently become a trial company in the Energy Efficiency Opportunities Programme (EEO) managed by the Australian Government's Department of Industry Tourism and Resources. This programme targets businesses using more than 0.5 PJ of energy per year. It has the potential to improve the competitiveness and sustainability of individual firms through energy management, while also delivering many significant economic, environmental and investment benefits for Australia.

Businesses participating in the EEO programme will be required to undertake a detailed energy assessment every five years to identify opportunities to improve energy efficiency, and to report publicly on the outcomes. Companies are not required to implement the opportunities they identify. The Australian Bureau of Statistics estimates that approximately 250 companies use more than 0.5 PJ of energy per year. Together, these companies account for approximately 60% of all energy used by Australian businesses. Improvements in the energy efficiency of these companies are therefore likely to have significant overall impacts on energy use in Australia. Although the EEO programme does not cover the operation of

RBVMs (since the energy use is paid by the Agent), the fact that the leading market operator is actively involved in energy efficiency issues may help in addressing these issues.

There is a choice of 12 different models of RBVMs and two additional combination drink/snack machines. Each machine has different features, including electricity consumption, whether an energy conservation mode is available and whether the 'Harvest' system of networked alerts for restocking and security is included.

However, the information on energy usage is limited to a figure for current usage (which is likely to be compressor motor rating, not daily energy) and no details are provided about the energy savings when an energy conservation mode is used. Meaningful information on energy efficiency and the choice compared with those offered on the Japanese market is very limited. Again, it should be noted that cost saving data for using an energy-efficient machine is difficult to obtain and available data may not allow sufficient information for an agent to assess true operational costs.

A major player in the operation of vending machines in Australia, Coca Cola Amatil, could source highly efficient machines manufactured for the Japanese market, but they instead source machines from the USA, the location of its parent company. The recent efficient US 'Tier 1' machines typically use 9.9 PJ/year per unit (NAEEEP, 2004) whereas the Japanese machines use 8.3 PJ/year/unit (Takahashi, 2006), although it is difficult to establish the comparability of the energy use tests. Further financial analysis is required to establish how both principal and agent can benefit by increased machine cost to the principal and lower operating cost to the agent.

Conclusions and recommendations

Policy options and recommendations

Different options are available to address the PA problems affecting the RBVMS market in Australia. These are identified in the MEPS and include:

- requiring improved lighting (subject to the 2003 MEPS for lighting);
- using external motion sensors to turn on lighting only when a potential;

- customer approaches the machine;
- adopting new technology for networking machines to improve efficiency of restocking operations;
- improving automated switching to manage power usage during low usage periods;
- labeling machines to better inform the Agent of their operating costs;
- retrofitting the high efficiency components during refurbishment;
- legislating the MEPS;
- leveraging the engagement of market leaders to use more energy-efficient machines;
- incorporating fuzzy logic control; and
- using daily/weekly timers to take account of low use periods.

The detailed information presented in the MEPS and the announcement of an agreed test procedure for measuring energy efficiency of the machines provide a basis for further work on this issue. However, the prospects for major improvement may be determined by the economies of scale which influence machine purchases from the USA.

Conclusion

PA problems conforming to Case 2 primarily affect the refrigerated beverage vending machine market. In this case, the vending machine owner-marketer supplies a limited range of rather inefficient machines and the building owner pays for the electricity. The vending machine operator is not aware of, or does not have access to, direct energy consumption costs or indirect energy costs (such as increased air conditioning loads).

The reforms in the National Energy Market and the progressive use of 'Smart Meters,' combined with application of Minimum Energy Performance Standards, offer the potential to reduce the current high energy use of Australian vending machines through regulated requirements and better consumer information.

PA problems affect an estimated total of 416 GWh of energy per year in Australia. This study estimates the payback of more efficient machines at 0.74 years (National Appliance and Equipment Energy Efficiency Program, 2005).

Australia imports the majority of its vending machines from the United States. The number of all types of refrigerated machines per unit of population (148 500 machines in a population of just over 20 million, equivalent to one machine for every 135 Australians) is significantly lower than Japan (1: 23) and the United States (1: 39). This suggests the potential for growth in vending machine energy use in Australia if their use approaches the level in the US or Japan.

The MEPS is the major government strategy for increasing energy efficiency of RBVMs, although greater savings may be possible if PA problems could be addressed. Because most RBVMs are imported from the US, it will be necessary to find a way to import more efficient machines or to revise the MEPS to a higher standard. The dominant market player appears to import RBVMs from the US since that is the home of its parent country and because the US is a major manufacturer of these machines.

A draft Australian standard for test methods and draft MEPS for RBVM have been issued for public comment. The MEPS document is subject to a regulatory impact statement.

The mooted introduction of MEPS in 2007 is aimed at increasing the use of energy-efficient machines by effectively removing inefficient machines from the market. The MEPS study (National Appliance and Equipment Energy Efficiency Program, 2005) is based on a lifespan of 10 years with a 2% annual growth in numbers of machines deployed. Even with this combined rate of replacement and growth, the MEPS could take some years to achieve a substantial impact.

Other factors that may constrain the RBVM market include the progressively tougher stance schools are taking on the sale of sugar-laden drinks to counter a widely reported childhood obesity epidemic. Similar issues are arising in the USA and other countries. A Canberra-based operator of RBVMs commenced operation in early 2006 and markets 'healthy choices' that responds to this issue. This operator returns a portion of the earnings to the agent and also took into account the energy consumption of the vending machine (which is a combined type) in developing the business plan (J. McCown, 'Going Healthy', personal communication, May, 2006).

Publications including *Managing Energy in Local Government- E12 Refrigeration* (Australian Greenhouse Office, 2003) provide information on energy savings opportunities for vending machines to local governments and general consumers.

For the agent, the main issue is usually the rate of return on investment, not the electricity bill. Relatively low energy costs in Australia mean that energy savings will not provide sufficient incentive by itself. Factors other than energy efficiency may be more important, such as a good location or an optimal range of products. In comparison with other costs and profits, energy costs are a relatively minor factor. A RBVM using 0.027GJ/day will typically cost less than AUD 300 per year in energy costs, equivalent to sales of approximately 150 drinks.

There is considerable scope for improving information dissemination on the vending machine's energy efficiency. Indeed there is an apparent problem with the current information available. Both vending operator industry associations contacted by the author confused the 'C tick' requirements (an Australian and New Zealand standard for electrical equipment to prevent electromagnetic interference) with an energy efficiency rating.

Conclusions

15 Conclusions and policy implications

16 Annex

CONCLUSIONS AND POLICY IMPLICATIONS

This book has found significant evidence of untapped energy saving potentials resulting from PA problems in all three sectors studied. The table below summarises the findings. The table shows a range of impacts of PA problems – from negligible (Japan vending machines) to around 30% of total sectoral energy use (US residential). In absolute terms, the total energy affected amounts to 3 817.9 PJ/year – around 85% the total energy use of Spain in 2005.

TABLE 47

Summary of results from all case studies

	Energy use affected by PA problem (PJ)	Total sectoral energy use in 2005 in the relevant country (PJ)	Energy use affected by PA problem as a % of total sectoral energy use
Residential sector			
Refrigerators, space heating, water heating and lighting, US	3 546.0	11 296.5	31.4%
House heating Netherlands	105.0	433.0	24.3%
Set-top boxes US	68.4	11 296.5	0.6%
Commercial sector–office space			
Japan	60.5	2 575.1	2.3%
Netherlands	24.5	316.6	7.7%
Norway	5.4	103.2	5.2%
End-use appliances: Vending machines			
Japan	6.1	2 575.1	0.2%
Australia	1.5	243.5	0.6%
Total	**3 817.4**	**28 839.5**	**14.3%**

The analysis of the case studies leads us to draw *four* main policy lessons:

- There is strong evidence that PA problems affect the level of energy efficiency in a range of settings.
- There are no silver bullets to solving PA problems. PA problems are pervasive and disbursed and therefore difficult to resolve with a single policy instrument. Solutions to PA problems require a mix of policy instruments:
  - It is important to ensure that the contracts are designed so all relevant actors face the energy price – in other words "making the price more potent".
  - Best-practice regulatory instruments for energy efficiency (building codes, minimum quality standards for tenancies etc as you note) are also needed as a way of limiting the impact of (any residual) PA problems.
  - It is important to ensure the availability of adequate information on energy efficiency to principals and agents.
- The effectiveness of solutions to PA problems is dependent on national context.
- Further analysis of PA problems is needed.

Evidence of the PA problems

This study establishes strong evidence of the existence of PA problems in several energy markets. The evidence presented is all the more telling considering the conservative assumptions that were made throughout the calculations. Furthermore, the findings in this book demonstrate that the magnitude of energy affected by PA problems is significant.

Given that PA problems belong to the set of market failures, our analysis adds weight to the need for governments to investigate the potential for intervention to address this market failure. Experience has shown that well-targeted policies could help reduce – and even eradicate – the PA problems (*i.e.* Japan vending machines).

No silver bullet: comprehensive policy packages needed to address PA problems

PA problems are pervasive, dispersed and complex and, as such, no single policy will fully overcome this market failure. Instead, Governments should help design well targeted policy packages to address PA problems in their specific national contexts, and within the particular constraints of a given sector. Case studies underline that without such a policy approach to addressing the relationships between principals and agents, policies will have limited effect on PA problems. Here the case of the Netherlands and the US residential sector are telling: despite early imposition of regulatory mechanisms, the PA problems have persisted.

The importance of a mix of policy instruments packages is further illustrated by the Netherlands commercial office case. In an attempt to fulfil their Kyoto targets, the Netherlands government put in place regulatory mechanisms through the establishment of MEPs (*i.e.* EPN). This policy has achieved a 20% reduction in energy consumption in the last 10 years. Yet, a SenterNovem study reveals that should the provision be removed, energy consumption would soon return to pre-policy levels. In other words, the regulatory instrument did not necessarily succeed in addressing some of the fundamental issues that influence energy consumption – such as PA problems. In fact, both commercial and residential case studies in the Netherlands show evidence of large PA problems (7% and 24% of all energy use in each sector respectively).

In contrast, the Japanese vending machine and display cabinet case studies illustrate that a policy-package approach can overcome the PA problems. In this case, the combination of the Top Runner Programme, in conjunction with regulating the contract template (*i.e.* a change in the nature of the contract linking the principal and the agent) has helped address the PA problems.

What then are the essential elements of a policy package to address PA problems? This study has identified the following 3 critical components.

Redesigning contracts to make the price more potent

An important dimension to reducing PA problems is, wherever appropriate, to break the isolation of both principal and agents from the energy price signal – making the price more potent. A key to making the price more potent is to redesign the energy-related components of contracts between principals and agents. That is, the energy-related aspects of contracts should be redesigned to ensure all parties that are involved in energy use decisions (whether that be the tenant-energy user, or the landlord-appliance purchaser) face energy price signals.

Contracts are an integral part of market operation. By aligning responsibilities for paying energy bills and choosing the technologies, contract design can help overcome the PA problems. In contrast, poorly designed energy-related components of contracts, which are currently common in landlord-tenant situations, can reinforce split-incentives and information asymmetry between the principal and the agent, thereby leading to sub-optimal energy use decisions (Aghion and Bolton, 1987).

The Japanese vending machine and display cabinet case illustrates how adequate contract design can help overcome the PA problems. In this case, the Japanese government regulated vending machine contracts to make the beverage distributor responsible for both the vending machine choice and the payment of the utility bill. By eliminating the building owner from the energy transaction, the new contract ensured that energy-related goals were aligned. In doing so, the government helped to eradicate PA problems in this sector.

The role of governments in influencing the design of the energy-related aspects of contracts needs to be carefully considered. In market economies, the content of individual contracts is left to the contract parties. However, experience shows that markets are unlikely to ensure that the energy-related aspects of contracts adequately take account of energy efficiency.

In this regard, it is useful to remember the essential role that the Japanese government played in altering the contract template for vending machines. The experience with Japanese vending machines leads us to consider that such a government-led solution may be possible in other contexts. While it may be difficult to replicate the vending machine solution in other situations (such as landlord-tenant contracts), governments should still investigate the potential for removing PA problems in their jurisdictions by influencing the design of energy-related aspects of contracts. Essentially, wherever appropriate, and where changes do not result in perverse outcomes, governments should encourage the adoption of new contract templates to ensure all parties that are involved in energy use decisions face energy price signals. At a minimum, relevant contracts should be designed to split the energy bill between the principal and agent.

Implementing best-practice regulatory instruments

It is unlikely that contract redesign is going to totally remove the PA problems in the short to medium-term. For one thing, many existing contracts affecting PA problems will not be able to be amended until they come to term. In this context, it is also essential to implement best practice policies that regulate the level of energy efficiency in appliances and buildings. Ensuring that such minimum energy performance standards and building codes are in force and continually updated with help to limit the impact PA problems have on energy use. For example, in a landlord-tenant situation where the landlord supplies the appliances and the tenant pays the utility bill, the impact of the PA problems on energy use will be limited if MEPS exist. MEPS will limit the landlord's choice to appliances that meet a minimum level of energy efficiency.

Ensuring the availability of adequate information

Another important element in overcoming the PA problems is the provision of easily accessible information about energy efficiency. Providing information on energy efficiency can help both principals and agents ensure that energy-related decisions are as energy efficient as possible. Studies show that in many parts of the world public knowledge about the potential benefits of energy efficiency and how to implement energy savings remains weak (Ademe, 2006).

There is room here for both government intervention and private providers to help increase public awareness of energy efficiency. Governments have in the past engaged in successful energy efficiency related information campaigns. Such campaigns need to address all elements of information failure – its accessibility and comprehensiveness – and should aim to have an enduring effect.

Further, an energy efficiency information campaign is a useful complement to ensure the success of other energy efficiency policies. Case studies emphasise that the most effective policies happened in countries where popular adherence to energy efficiency was already high – like in Norway in times of energy crisis (winter 2002-03), or in Japan due to the historic dependence of the country on foreign imports which result in a long time popular knowledge of energy-efficient advantages.

The private sector also has an important role in providing information. Consumer-related magazines such as *Consumer Reports* in the USA and *Consumer* in New Zealand fill an important market niche and provide essential energy-efficiency related information.

The influence of national context

The national context plays a key role in the potential success or failure of energy efficiency policy. Important contextual factors include institutional support for energy efficiency, the price of energy and public awareness of the importance of energy efficiency. The latter two points in particular have emerged as important influences on PA problems.

The Japanese and Norwegian cases in the commercial sector both illustrate the importance of energy price and public awareness of the PA problem. Where Norway has relatively cheap and abundant energy resources through its hydroelectric infrastructures and hydrocarbon exploitations, Japan is a resource-constrained country dependent on foreign energy imports. These contrasting situations have led to different levels of familiarity and support for energy efficiency initiatives in the two countries. For example, Norway started applying energy-efficient policies in the late 1990s, the programs have had difficulty in genuinely altering energy markets (Enova, 2007).[59] The relative lack of public familiarity with energy efficiency issues and the absence of an adequate awareness campaign might explain the difficulty Norway has had in implementing energy efficiency programmes.

In contrast, the relatively high level of awareness of the Japanese to energy efficiency and conservation is perhaps part of the explanation for the low level of PA problems in the two Japan-related cases. The Japanese have successfully addressed PA problems in the vending machine industry. Similarly, we find only a relatively small presence of PA problems in the Japanese commercial office space (1.5% of the whole sector compared to 15% and 40% for the Netherlands and Norway respectively).

A need for further analysis

Another conclusion of the study is that there is a need for more systematic analysis and quantification of PA problems and other barriers. Evidence presented in the study is only the tip of the iceberg and suggests more systematic analysis could be beneficial in understanding the extent of PA problems and other barriers to energy efficiency. This study had limited scope: confining itself to the PA problems within the market failures notwithstanding others failures such as internal firm failure, information asymmetries etc.

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59. Personal communication.

Further research should focus on two areas. First, we recognise that the calculations in this book rest on many assumptions. Useful effort could be applied to collating more data to refine the estimates made in this book. Second, it is important to expand the scope of this type of analysis, both across more situations where PA problems may occur and to other barriers. This study considers only a subset of market barriers: PA problems. As discussed in Chapter 2 other barriers could also benefit from an attempt to quantify their magnitude.

ANNEX

US residential case study (from Chapter 9)

Refrigerators

Calculation of the number of housing units falling in Case 1

To estimate the number of housing units falling in case 1, this study began with occupant-owned SFRs. In newer units, the refrigerator is often pre-installed by the builder. According to NAHB, refrigerators were pre-installed by builders (and are thus not chosen by the user) in 45% of new SFR units. The AHS provides figures on housing completions by use (owned vs. rental) for five-year increments. According to AHS, 15.7 million occupant-owned units have been built since 1990. About 95% of the occupant-owned units in the housing stock are SFRs or mobile homes, so newer housing completions were apportioned into SFRs and MFRs on the same basis. Applying this share and the figures from NAHB results in 8.2 million newer occupant-owned SFRs, that is the 55% of new occupant-owned households where the occupants select the refrigerator.

The past fifteen years worth of occupant-owned housing completions were simply subtracted from the occupant-owned stock (with a slight adjustment for condominiums where electricity appears to be included in a condominium fee) resulting in 53.7 million SFRs where occupants have chosen a new refrigerator to replace an old one. This study assumes that SFR renters probably have the opportunity to choose their own refrigerators more often than MFR renters, so a higher percentage was used. Using a share of 25% of rental SFRs where renters supply their own refrigerators results in 3.0 million units.

For MFRs many of the same factors were considered. Using AHS figures this study determined that roughly 0.9 million of the 3.6 million occupant-owned MFRs had been built in the last fifteen years. According to NAHB, 85% of new MFRs have a pre-installed refrigerator so only 0.1 million occupant-owned MFR households fall into case 1. Taking the stock of older condos and subtracting out the number where utilities are included in rent adds another 2.5 million units to case 1. Finally, using the NAHB data, this study assumed that in the 15% of rental MFRs where the landlord does not provide the refrigerator, the utilities are never included in the rent. Thus, the entire population of 3.2 million MFR units with no refrigerator provided also belongs in case 1. In all, there are 70.8 million household in case 1, most of which are SFRs.

Several assumptions were made to calculate the numbers for Case 1: 1) newer occupant-owned units have the same SFR/MFR split as the existing occupant-owned stock; 2) occupants choose refrigerators in 25% of rental SFRs (slightly more than in MFRs); 3) the percentage of new MFRs with refrigerators supplied in 2003 applies equally to all newer MFRs whether occupant-owned or rented and to older rented MFRs as well; and 4) the NAHB percentages of SFRs with refrigerators preinstalled for 2003 were used for all SFRs built since 1990.

Assumptions behind estimates of the possible savings from one year of refrigerator sales if all refrigerators sold that year were not affected by these split incentives.

The AHAM Factbook 2003 shows that the shipment-weighted average energy consumption in 2002 was 520 kWh/year. It also provides a figure that 25% of refrigerators shipped that year qualified as ENERGY STAR models. By definition, ENERGY STAR refrigerators are those that use at least 15% less energy than the current federal standard. If the 75% of non-ENERGY STAR refrigerators all just met the standard and the ENERGY STAR refrigerators exactly met the ENERGY STAR threshold, the shipment-weighted average would be about 4% lower than the average if all refrigerators only met the standard. Since some ENERGY STAR refrigerators use less than 85% of the energy than the minimum standard for their category, and some models are slightly less than the standard but not ENERGY STAR models, this study assumed that the shipment-weighted average was 6% lower than the minimum standard. In other words, the shipment-weighted average falls between the minimum standard and the ENERGY STAR threshold. In order to estimate the savings that might arise from eliminating the PA barrier, this study assumed that households not affected by PA barriers will buy refrigerators whose efficiency falls halfway between the shipment-weighted average and the minimum ENERGY STAR threshold, which means, on average a refrigerator that uses 495 kWh/year. Thus, for every household where the PA barrier is eliminated, 25 kWh/year will be saved.

Using census data on housing completions for 2003 (US Census Bureau, 2005b), this study estimated that 0.87 million of the 9.87 million refrigerators shipped in 2003 were for new units with pre-installed refrigerators. Subtracting out refrigerators needed for the rest of the 0.81 million new housing units leaves

8.19 million refrigerators purchased for replacement of refrigerators in existing residences. Multiplying total replacements by the share of rental units with renter-paid electricity in the total housing stock yields an estimate of 2.27 million refrigerators purchased on behalf of renters who pay their own electricity bills. This totals to 3.14 million refrigerators shipped in 2003 (32% of all refrigerators shipped that year) for use in residences affected by Principal-Agent problems. Multiplying that number of refrigerators by the estimated savings of 25 kWh/year suggests that annual savings from a single year's worth of sales would be 78 million kWh or 0.78 primary trillion Btus/year.

Water heaters

Calculation of the number of housing units falling in Case 1

The average lifespan of a water heater is approximately thirteen years. In order to calculate the number of units with no Principal-Agent problem (Case 1), the occupant-owned SFRs (including mobile homes) where the water heater has been replaced at least once were estimated by subtracting the number of occupant-owned SFR units constructed between 1990 and 2003 (estimated from AHS data – 95% of all occupant-owned units constructed in that period) from the total number of occupant-owned SFRs. Then, 40% of this difference results in 21.6 million SFR and mobile home households in Case 1 with no Principal-Agent problem. In order to determine which occupant-owned MFR units have no Principal-Agent problem, older condos with central boilers or with the water heating fuel included in fees are subtracted from the set of older condos. Data limitations in the AHS tables did not allow a cross-tabulation of condominiums by water heater fuel and fuel types included in fees. However, 0.9 million occupant-owned MFR units are listed as having a steam or hot water heating system (US Census Bureau 2005a). Adjusting for the number of those that are greater than thirteen years old leaves 0.7 million units. Subtracting this number from all older occupant-owned MFRs and multiplying by 40% places another 0.8 million households in Case 1 for a total of 22.4 million households.

Cases 2 to 4

Case 2 consists of most rental units, all newer occupant-owned residences, and 60% of older occupant-owned residences. This study assumed that new home or condo buyers rarely specify the model of water heater to be installed. The AHS data shows 15.7 million occupant-owned residences were completed in the past thirteen years. From these this study subtracted the 0.19 million newer condos that have central steam heating systems, which this study assumed also provides hot water. These were moved from Case 2 to Case 4 since units with centrally heated water will not be billed individually for the water heating fuel. The 0.68 million older condos with central steam or hot water systems also fall into Case 4.

For older occupant-owned residences where the water heater has been replaced at least once, but the occupant did not choose the water heater because of a catastrophic failure of the water heater, 60% of the older SFR and mobile home stock yields 32.3 million households in Case 2. To calculate the condo units that fall into Case 2, the number of older units was adjusted by the estimated units with central water heating. Of those 1.9 million households, 1.2 million are assigned to Case 2.

In addition to a large portion of occupant-owned units, this study included all rental units in Case 2, except those where the water heating fuel is included in rent, which fall in to Case 4. Since the AHS data only indicate the number of housing units for which a given fuel's cost is included in rent or other fees, this study made some assumptions to estimate the number of households whose water heating fuel is included in rent or fees. Using AHS data, this study allocated the rental units with electricity included in rent to households assumed to use electricity as water heating fuel using the ratio of electric water heating units in the entire rental stock. For the number of rental units listed as having natural gas or fuel oil included in rent or fees, this study assumed that all of these units have water heating by those fuels since these fuels are generally used for both space and water heating when available. Of the 33.6 million rental units, this study estimated 11.0 million fall into Case 4, and the remaining 23.5 fall into Case 2. Due to data constraints this study did not calculate households belonging to Case 3, but the number of households falling into Case 3 would be negligible.

Description of results

In order to calculate the energy consumed for water heating by the 83.5 million households that are affected by PA problems, the total number of affected units was disaggregated by household type using the AHS data. This was necessary because average energy consumption for water heating varies by unit type.

According to RECS, the energy used for water heating varies from 10.5 GJ in households in MFR buildings with 5 or more units to 18.9 PJ in SFRs (US EIA, 2004a). Averages for smaller MFR buildings and mobile homes were in between. Multiplying the number of households by the RECS average water heating energy consumption for each household unit type yields an estimate of 1 365.2 PJ of delivered energy affected by PA problems.

Estimating total primary energy affected required additional steps in order to produce a separate estimate on the share of electricity in the total energy affected by PA problems. RECS figures on total consumption by household by fuel and household type were apportioned to units on the basis of the shares of each type of housing unit affected by PA problems. For example, this study estimated 54.2 million of 74.0 million (non-mobile) SFR households to be affected by PA problems for water heaters. Total natural gas consumed for water heating in SFRs was 981 PJ. This study estimated approximately 73% (54.2 million divided by 74.0 million) of the natural gas consumed for water heating to occur in SFRs affected by PA problems. Continuing this calculation for the other fuels and household types results in 1 073 PJ of direct fossil fuel combustion and 292.2 PJ (80.7 billion kWh) of electricity. This is approximately 77% of the 1 772 PJ RECS shows for total water heater site energy and 13% of total residential site energy consumption. Multiplying the total for electricity by the primary energy factor described above yields 857.8 PJ of primary energy for electricity for a total of 1 918 PJ of primary energy or 10% of total residential primary energy.

Estimate of annual savings from one year's worth of water heater sales

Data from the Gas Appliance Manufacturers' Association show that 9.55 million water heaters were shipped in the US in 2003 (GAMA, 2005). A small number of LPG and fuel oil water heaters are sold, but GAMA does not supply data on them. Among gas and electric water heaters, 54% were gas.

The Census data on housing completions allowed this study to determine how many water heaters were needed for new SFRs (1.3 million), MFRs (0.3 million), and mobile homes (0.07 million) (US Census Bureau, 2005b; US Census Bureau, 2005c). This leaves 7.9 million water heaters purchased as replacements. Of these, this study assumed that 60% were purchased as emergency replacements. Since this study did not have data on main water heating fuel by year of completion, the 2003 total shares of gas and electric water heaters were applied to each category of housing type. These were allocated to rental units by unit type on the basis of the share of each rental housing unit type in the total stock. For example, since rental MFRs constitute 20% of the total housing stock, 20% of the replacement water heaters purchased were assumed to be for rental MFRs. Altogether, an estimated 4.0 million gas water heaters and 3.4 million electric water heaters shipped in 2003 (more than 77% of all water heaters shipped that year) were subject to PA problems.

With RECS data on average water heating consumption by housing unit type and fuel, this study finds that 80.2 PJ of natural gas and 31.7 PJ of electricity (173 PJof total primary energy) will be consumed by these water heaters each year. Using LBNL data on average annual water heater energy consumption by fuel type (Meyers 2005) and ENERGY STAR data on the energy consumption of the most efficient water heaters sold in 2004 (US DOE, 2004), this study determined that the best available natural gas water heaters in 2004 were 20% more efficient than those meeting the minimum 1990 standard and the best available electric water heaters were 10% more efficient. As a rough approximation of incremental energy savings in the absence of PA problems, this study split the difference between the minimum standard and the best available. This study estimates that without PA problems, annual savings from 2003 sales of water heaters would amount to 9.6 PJ of site energy and 12.6 PJ of primary energy. As an additional estimate of potential savings, this study estimated that annual savings from individual billing of the entire stock of units included in Case 4 could be as high as 15.8 to 31.7 PJ, assuming a 10% to 20% reduction in usage due to billing. This range was selected on the basis of a study on the impact of submetering on water use in MFRs that found an average 15% reduction compared to master-metered apartments (Mayer *et al.,* 2004).

Space heating

Calculation of the number of housing units falling in Case 1

Similarly to water heating, Case 1 households are composed essentially of older occupant-owned units, in which occupants have had to replace original equipment and therefore had the opportunity to choose it. In order to determine the number of households in Case 1, the number of older units must be disaggregated by unit type. This is particularly important for space heating since the per household average energy consumption for heat differs widely among

SFRs, MFRs, and mobile homes. AHS only provides data on year of construction by tenancy status (owned vs. rented) but not by unit type. Like previous calculations, the newer occupant-owned units (those built since 1985) were separated from the whole stock. It was assumed that the proportion of condos and mobile homes among all occupant-owned units has not changed significantly over time, so these older units were allocated to unit types based on the proportions in the total stock. A correction in the number of condos was made to account for those units served by central steam boilers. The number of condos with central steam heating was divided into newer and older units in proportion to the newer and older shares in the total stock of condos. These calculations resulted in 44.9 million SFRs; 1.8 million MFRs, and 3.9 million mobile homes falling in Case 1. Together, these households consume approximately 2 584.9 PJ of site energy per year for space heating, or about 53% of site energy for heating.

Case 2

Case 2 households consist of mostly rental units and those occupant-owned units built within the last 20 years. Rental units with fuel costs included in the rent and newer condos with central steam heating systems are the exceptions. The number of boiler-heated condos was determined for Case 1, so these were subtracted from the stock of new condos.

In order to determine the number of units where the space heating fuel cost is included in rent, some reasonable assumptions had to be made because the AHS data do not cross-tabulate the main space heating fuel by whether that fuel is included in rent. This study assumed that for apartments where electricity is included in rent, electricity is not the main space heating fuel, reasoning that landlords would shield themselves from the large expenditures that electric heating can entail. In contrast, this study assumed that where natural gas or fuel oil is included in rent or other fees, they are the main space heating fuel. This study assumed that fuel oil and gas are rarely used by the same household, although it is possible that some apartments with fuel oil fired central steam or hot water heating could also have natural gas for water heating and cooking. This study assumed this number is small. Calculations result in 29.1 million SFRs, 14.5 million MFRs, and 2.5 million mobile homes in Case 2. These homes consume approximately 1 962.4 PJ of site energy for space heating, about 40% of the total.

Case 3

These units would consist of condos with individual electric or natural gas heaters where that fuel is included in condo fees. However, this study assumes this number to be negligible.

Case 4

Case 4 units consist of the rental units with space heating fuel costs included and condos with central steam systems. This amounts to 8.7 million MFRs and 0.5 million mobile homes. These units consume 369.3 PJ of site energy for heating, which accounts for 8% of the total heating energy.

Analysis and implications for all four end-uses: sensitivity analysis of key assumptions

This study had to make many assumptions to estimate affected energy and energy saving potential for the end-uses described above. Most of these assumptions concerned the allocation of the housing stock into various levels of housing unit type, tenancy status, inclusion of fuel costs in rent or other fees, and main fuel type for space heating and water heating. Assumptions were necessary due to a lack of data for various combinations of these criteria. In other cases, a data point existed for one year and had to be applied to other years for which data were missing. Rough estimates were also made of the energy usage for some end-uses and the effect on consumer choices from removing PA barriers.

This study conducted a sensitivity analysis to investigate the effect of changing the values for the key assumptions. Values were increased or decreased based on reasonable counter-assumptions, and the corresponding changes in energy consumption or savings were noted. The results, organised by end-use, are shown in Table 48.

The assumption with the largest impact on the energy used by refrigerators affected by PA problems concerns the retroactive application of the share of SFRs built in 2003 that had refrigerators pre-installed (45%). Because this study did not have data to indicate whether this figure has remained relatively steady since 1990, this study changed the assumed average share by ± 15% to account for the possibility that the share of pre-installed refrigerators was significantly higher or lower in previous years. A figure for a shipment-weighted minimum standard[60] was not available and had to be estimated using the shipment-weighted average. Since ENERGY STAR refrigerators are those that use at least 15% less energy than the minimum standard in their class, this study assumed that the shipment weighted average is between the minimum standard and the ENERGY STAR level and back-calculated the shipment-weighted minimum based on a 6% difference between the average and the minimum standard. A large impact was observed on estimated savings based on changing the value of the difference between the shipment-weighted average of all refrigerators shipped for the US market in 2002 (AHAM 2003) and what the shipment-weighted value would have been if all refrigerators had only been manufactured to meet the minimum standard. Slight changes in the assumed difference between the average and minimum standard have a large impact on the savings potential.

For water heating, the main assumption influencing the estimate of affected energy is that new home buyers never choose their own water heater. Changing that assumption to allow 20% of new home buyers to select their own water heaters decreases the affected energy by 7.5%. The assumption with the largest impact on the estimate of annual savings from eliminating PA problems for year 2003 sales is the percentage improvement in water heater efficiency that would result from this alone. Halving the efficiency improvement to only 2.5% for electric units and 5% for gas units also reduces the savings estimate by half. The largest impact on savings that would result from individually billing the stock of rental units where fuel costs are included in rent or fees is the assumption that units reporting natural gas included in rent are reporting accurately, and that these units use natural gas as their heating fuel. Assuming that half of these units are misreports lowers the savings estimate by a third.

The estimate of affected energy used for space heating is strongly influenced by two values. The first is the assumption that new home buyers never choose their own furnaces and other heating-related features. In many cases this may not be true. If the percentage of new home buyers selecting their own heating and insulating features were 20%, affected energy use would fall by 13.5%. For heating, it is difficult to define precisely what constitutes a "new" occupant-

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[60] Since the value of the standard depends on the size and features of refrigerators, a single standard for the typical refrigerator would have to be calculated using the standard for each model of refrigerator and share of that model among the total or shipped.

owned house, since multiple features affect demand for heating fuel. This study chose 20 years based on a rough estimate of furnace lifetime, which results in 29% of occupant-owned units. Increasing or decreasing that share by 7% (about a fourth of the “new” population) yields a corresponding change in affected energy of ± 11%.

For lighting, the main assumptions concern the accuracy of the units reporting electricity as being included in rent or other fees in the AHS (US Census Bureau 2005a). Of particular importance is the assumption that the AHS figures are accurate for rental MFRs and mobile homes.

Table 48

Critical aspects of an Agency Theory enquiry (based on Sharma, 1987)

Description of assumptions used	Counter-assumptions	% Change in affected energy	% Change in savings from one year's sales
Refrigerators			
Since only one year's data (2003) were available from NAHB on the rate of pre-installed refrigerators, the same rate was assumed to apply for all "new" stock of SFRs.	Assume that the rate has changed markedly over time, and that previous years had either a much higher or lower rate of pre-installs than 2003 resulting in average rate for all 15 years changing by ± 15%.	± 7.5%	
Data provided by NAHB did not differentiate between condo and rental MFRs. This study assumed the same rate applied to both.	Assume condo buyers chose refrigerator 45% of the time, the same rate that applies to new SFRs.	- 0.80%	
Rate of pre-installed refrigerators for 2003 MFRs applies to entire rental MFR stock.	Assume that on average 95% of MFR renters do not choose refrigerator because NAHB data do not capture instances where landlords have refrigerators installed after construction is completed.	5.40%	
Because communication with Census Bureau staff led us to believe that many HH reporting gas and electricity included in rent are misreports, particularly SFRs, this study assumed that all rental SFR units with electricity included in rent are misreports.	Only half of rental SFRs with electricity included are misreports.	2.00%	
Since some rental SFRs do have electricity or gas included in rent, this study compensated by assuming that all MFRs reporting electricity included in rent are accurate.	Half of reported electricity included units are misreports.	- 5.40%	

Table 48 *(continued)*

Critical aspects of an Agency Theory enquiry (based on Sharma, 1987)

Description of assumptions used	Counter-assumptions	% Change in affected energy	% Change in savings from one year's sales
Most HH reporting a secondary refrigerator are SFRs. These refrigerators were divided proportionally among rental & occupant-owned SFRs based on their shares of the SFR stock.	Assume rentals greater or lesser than proportional share by ± 5%.	± 4.2%	
Assumed that 25% of SFR renters use own refrigerator, somewhat more than the estimate for MFR renters.	15% of SFR renters use own refrigerator, same as the estimated MFR share.	4.10%	
Shipment-weighted average for 2002 is 6% better than minimal standard.	Assume shipment-weighted average is closer to or better than minimum standard by ± 2%.		+20%
Water Heating			
New SFR and condo buyers never specify the type of water heater installed.	Assume 20% of new SFR and condo buyers choose water heater.	- 7.50%	
Replacements of water heaters by occupant-owners are done on an emergency basis 60% of the time.	Change the rate of emergency replacement by ± 20%.	± 15%	
Since the best performing units in 2003 were more efficient than the minimum standard by 20% for gas units and 10% for electric units, this study assumed the efficiency gain from eliminating Principal-Agent Problem is half the difference, 10% for gas and 5% for electric.	The estimate of the savings may be high since information barriers are likely to play as large a role as PA barriers. Assume efficiency gain is only 5% for gas and 2.5% for electric.		- 50%
All MFR reports of electricity included are accurate.	Half of MFR electricity included are misreports.[b]	- 3.7% site - 9.6% primary	

TABLE 48 *(continued)*

Critical aspects of an Agency Theory enquiry (based on Sharma, 1987)

Description of assumptions used	Counter-assumptions	% Change in affected energy	% Change in savings from one year's sales
For rental MFRs with electricity included in rent, the share of electricity as WH fuel is the same as entire rental MFR stock (43%).	Assume only 30% of rental MFR units with electricity included use electricity as WH fuel because landlords less likely to include electricity in rent where electricity used for large end-uses such as water or space heating.[b]	– 2.2% site – 5.7% primary	
All rental MFR units reporting natural gas included in rent are accurate.	Only half of rental MFR units reporting natural gas included in rent are accurate.[b]	– 33.3% site – 29.1% primary	
Space heating			
Units defined as "new" based on 20-yr furnace lifetime, resulting in 29% of units classified as new.	Adjust "new" units by ± 7%.	± 11.1%	
New home buyers never choose furnace, insulation, windows, etc.	20% of new home buyers choose space heating-related features.	– 13.5%	
Data on composition of housing by year of construction were not available, assumed that "New" occupant-owned units composed of SFR/MFR/mobile at same proportion as total stock.	Assume the case that increases energy consumption the most: all new occupant-owned units are SFRs.	+ 2.5%	

TABLE 48 *(continued)*

Critical aspects of an Agency Theory enquiry (based on Sharma, 1987)

Description of assumptions used	Counter-assumptions	% Change in affected energy	% Change in savings from one year's sales
Lighting			
All rental SFRs with electricity included are misreports.	Only half of rental SFRs with electricity included are misreports.	+ 12.4%	
All rental MFRs and mobile homes with electricity included are accurate.	Half of rental MFRs and mobile homes w/ electricity included are misreports.	– 45.0%	
All occupant-owned mobile and MFRs with electricity included are accurate.	Half of occupant-owned MFRs with electricity included are misreports.	– 5.0%	

[a] Effet on site energy unless otherwise noted.

[b] Assumptions and sensitivity results also apply to the stock-wide estimated savings from individual metering.

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