The Pattern of Energy Efficiency Measures amongst Domestic Households in the UK

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Preface

This Commentary constitutes the final report of a research project on consumers' decisions regarding energy saving in domestic buildings which has been undertaken at the Institute for Fiscal Studies, with financial support from the Department of the Environment. The authors are grateful to Richard Moore for his work in preparing the EHCS data used in this analysis, and for his detailed guidance over its interpretation. They are also grateful for advice and comments during the course of the work from Paul Baker, Richard Blundell, Alan Duncan, Jonathan Fisher, Nick Hartley, Dieter Helm, George Henderson, Costas Meghir and members of a DoE Steering Group. The views expressed in this report are, however, those of the authors, and not necessarily those of the Department of the Environment or any other government department, nor of IFS, which has no corporate views.

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Summary

1. Technical surveys of the UK housing stock have concluded that there is substantial scope for households to make investments in energy efficiency that would appear to be cost-effective on conventional investment criteria. Many of these apparently cost-effective measures have not, however, been undertaken. This report examines the reasons which may explain the incomplete take-up of apparently beneficial energy-saving investments.

2. The report attempts to analyse the decision by households to invest in energy efficiency measures using the tools of microeconomic analysis. It thus aims to complement existing studies on energy efficiency investment, including studies based on technical data and surveys of householders' perceptions and attitudes. The report is divided into two parts. Part 1 (Chapters 2-5) considers the economic basis for household decisions about energy efficiency investments. This part discusses the relevance of the various technical estimates of the scope for cost-effective energy saving to individual households' investment decisions, and sets out a number of possible forms of potential 'market failure' which may prevent individuals undertaking genuinely worthwhile measures.

3. Part 2 (Chapters 6-11) uses data from the 1986 English House Condition Survey to estimate an economic model of the pattern of possession of energy efficiency measures across individual households. The results of this estimated model are then used to assess the practical importance of the various potential sources of market failure set out in the first part.

Part 1: The Theoretical Framework

4. The energy efficiency measures which are the subject of this report are the various actions households can take to prevent energy loss from existing energy-using activities, principally domestic space and water heating. The range of measures includes the installation of loft insulation, wall insulation, double glazing, draught proofing, and hot water tank insulation. On a wider definition of energy efficiency, measures to improve the efficiency of heating systems and other capital equipment would also be important; however, these raise different issues, and we do not consider them in detail in this report.

5. Each of the insulation measures described above has the character of an investment decision: an initial outlay of the cost of the insulation is made in the first year, and benefits are gained in the form of decreased energy costs over a number of subsequent years. Investment calculations of the *net present value* of each of the insulation measures suggest that all (with the possible exception of double glazing) have a positive net present value and, hence, are cost-effective investments. This appears to be somewhat at odds with the current low level of possession of some of the insulation measures.

6. There are two broad reasons which might explain the apparent discrepancy. Firstly, as Chapter 3 describes, a number of the assumptions made in the calculation of the net present value may not fully reflect all the relevant costs and benefits that a householder might wish to take into account in making a decision to invest in energy saving. There may be important hidden costs in the form of 'hassle' and DIY labour time which are not included in the calculations, and the results may also be very sensitive to the assumptions that are made about future energy prices and the appropriate rate of discount. A second explanation, and the one that this report attempts to examine empirically, is that there may be some important market failures affecting energy efficiency investments.

7. The possible sources of market failure are analysed in Chapter 4 under four headings: informational problems, non-optimisation, the difficulty of appropriating all the benefits from the investment, and credit market failures.

(i) Lack of information held by consumers can either be a simple problem of inadequate dissemination of existing information about the general properties of the various possible measures and their applicability to individual dwellings, or it can consist of a more intractable problem of the natural asymmetry of information between the buyers and sellers of insulation materials.

(ii) 'Non-optimisation' may arise where households make decisions about energy efficiency on the basis of inappropriate criteria. Even where households have ample information about the potential benefits of energy saving, the appropriate decision rule is complex and may be beyond the capacity of some householders.

(iii) Difficulty in appropriating the benefits of energy efficiency investments is in practice likely to be a problem closely related to the pattern of housing tenure. Cost-effective investments may not be undertaken if the person who benefits from energy efficiency improvements is not the person who pays for them. This may be a problem in owner-occupied houses where the current occupant expects to move before recouping the costs of the energy-saving measures, and there may also be problems in tenanted housing where the tenant bears the responsibility for paying energy bills but the landlord has responsibility for making any capital investments in the property.

(iv) Credit market failures may restrict certain sections of the population from investing in insulation measures because of their inability to borrow.

Part 2: The Empirical Model

8. The empirical analysis in this report uses cross-sectional data from the 1986 English House Condition Survey (EHCS) to model the household's decision to invest in energy efficiency measures, and to try to identify the practical importance of market failure. The EHCS data are particularly well suited to model household energy-saving decisions, since they include information both on the physical characteristics of the dwelling and on the incomes, energy spending, and other socio-economic characteristics of the current occupants.

9. We estimate models of two sorts. Firstly, we estimate a simple 'reduced form' model, in which each household's possession of loft insulation, wall insulation, or double glazing is related to a wide range of physical characteristics of the property and socio-economic characteristics of the occupants. In comparison with simple cross-tabulations of the data, this approach has the advantage that it allows the individual contribution of each of the factors to be assessed, independently of the effect of other, related, factors.

10. Given that the data relate to only a single year, we are restricted to a relatively simple 'one-period' model, which includes no dynamics and in which it is implicitly assumed that the socio-economic characteristics of the current occupiers are similar to those of the occupiers when the energy-saving measures were installed.

11. A second 'structural' model is also estimated. This is based on a simple system of two equations; the first equation describes the factors that influence the decision to insulate, one of which is the current consumption of domestic fuel, and the second equation describes those factors that influence the consumption of domestic fuel. The point of doing this is that it allows us to distinguish the *direct* effects of social and economic factors on the insulation investment decision from the possible *indirect* effects of social and economic factors on the insulation decision via their influence on energy consumption. Market failures would only be indicated by the influence of social and economic variables on insulation arising through the first of these channels.

12. Fuel consumption data are only available for a subsection of the entire sample, and the structural estimation of the system of equations is therefore limited to a sample size of about one-fifth of the original full data set. In practice, our results indicate that the more complex structural model is no significant improvement on the reduced form model, and in view of the greater sample size on which we can estimate the reduced form model, we have based our conclusions on the results from the full sample reduced form estimation.

13. Using the estimated model we calculate the predicted probabilities of possessing loft insulation, wall insulation, and double glazing under different household circumstances. These show, firstly, the range of factors affecting energy efficiency investments by households, secondly, how much some of the hypothesised market failures affect the possession of insulation, and, thirdly, how various inferences can be made regarding the influence of the unmeasurable sources of market failure.

14. The importance of many of the physical characteristics of the dwelling in explaining the pattern of possession of energy efficiency measures is consistent with the notion that some form of optimising investment behaviour underlies the pattern of individual household decisions. Variables which indicate such things as the size of the dwelling, the number of exposed walls, and the ownership of central heating are directly related to either the cost or the level of savings available from the installation of insulation. On the other hand, finding a relationship with central heating ownership could also reflect differences in awareness and attitudes to investments in that households investing in central heating may be better informed and may be the type of households that would be more likely to invest in home improvements.

15. As far as market failures are concerned, there is clear evidence of a strong effect from tenure. The probability of a household possessing any of the three measures studied is higher, other things being equal, amongst owner-occupiers than amongst private tenants, and the probability that a household has double glazing is higher amongst owner-occupiers than it is amongst council tenants. This suggests that the difficulty of appropriating the benefits of investments in energy-saving measures in private tenanted properties has led to under-investment in energy saving in these properties.

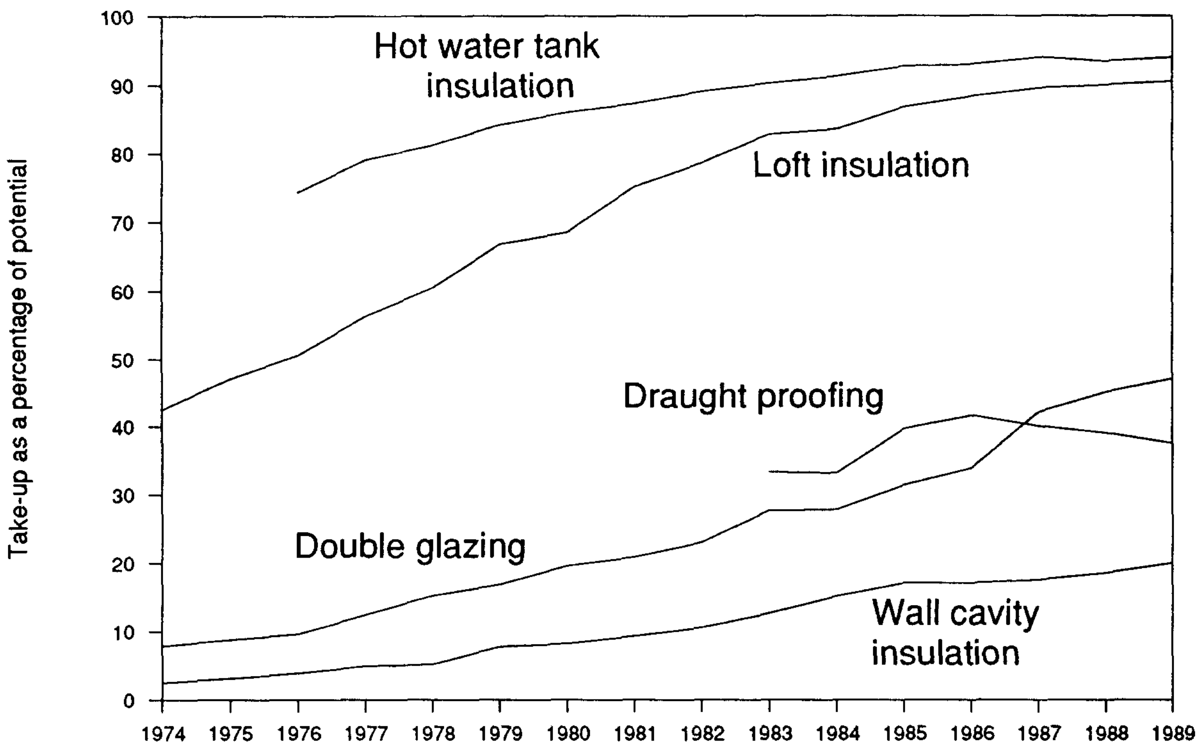
16. In comparison, evidence that the energy saving of segments of the population may be inhibited by credit constraints is harder to find. No effect is found on energy efficiency investment of long-term unemployment or the age of the head of the household - both of which may indicate groups particularly prone to credit constraints - and the effect of income is small and proportionally constant over different income groups. It is not possible to say from this analysis whether *all* households make decisions using discount rates which are inappropriately high or based on an unduly short time horizon. But this study finds no systematic differences between households that would suggest that credit constraints affecting certain groups of households more than others were a significant factor in explaining the take-up of measures found in the 1986 EHCS survey, in the economic conditions prevailing, and given the pattern of policy interventions at that time.

17. Finally, the low overall explanatory power of the models provides an indication of the importance of factors not included in the EHCS data and the estimated models. In each of the models a large part of the differences between individual households is not explained by the various factors included in the analysis. Whilst this is not unusual in cross-sectional estimation, it does indicate the considerable scope for factors not included in the EHCS data and the estimated models, such as attitudes and informational market failures, to have an effect on household energy efficiency investments.

1. Introduction

1. The oil shocks of the 1970s and the increasing environmental concerns of the 1980s have caused the UK government, along with the governments of many other industrialised nations, to promote energy conservation through various policy initiatives. There have generally been three types: firstly, schemes which aim to provide financial incentives through taxes and direct subsidies; secondly, policies to improve the information available to private decision-makers; and, thirdly, command and control policies which set standards or specify technologies that have to be used in new and/or existing houses.

Figure 1.1
The Possession of Energy Efficiency Measures



Note: The figures are calculated as the percentage of the housing stock in which it would be possible to install the specific energy efficiency measure.

Source: Henderson and Shorrock, 1989b.

2. During the same period, there has been a steady growth of energy efficiency investments by households (Figure 1.1). Whether the rapid increase in the take-up of domestic energy conservation measures over the past two decades reflects the impact of the oil price rises on individual behaviour, or the impact of the various government schemes, is impossible to assess with the information to hand, since both possible causes occurred at virtually the same time. There is reason to believe, however, that policy measures to encourage the take-up of energy efficiency measures are likely to continue to be of importance in energy and environmental policies, whether in conjunction with pricing policies or alone. Indeed, to the extent that such policies can succeed in removing sources of market failure at low cost, they may even constitute 'no regrets' policy measures - in other words, measures that would be desirable in themselves,

regardless of the future costs of greenhouse gas and acid rain emissions. Given the enormous range of uncertainty about the future environmental costs of current energy use, policies that yield benefits regardless of the magnitude of future environmental costs are clearly very attractive.

3. In the first half of this report we present a framework for assessing the factors underlying individual consumers' decisions regarding investments in energy saving in domestic buildings and for identifying the importance of possible sources of market failure, which policy measures might seek to correct. Chapter 2 sets out a theoretical structure for analysing the factors influencing domestic conservation decisions, and shows the relationship between energy prices and investments, and between investments and subsequent energy consumption. Chapter 3 describes estimates of the scope for cost-effective energy efficiency investments, and considers the extent to which they account for all relevant costs and benefits. Chapter 4 considers reasons why cost-effective energy investments might not be undertaken by some households; here the discussion is organised around certain sorts of 'market failure'.

4. The factors that influence the decision to invest in energy efficiency measures are an important consideration in assessing any policy proposals related to the reduction of domestic energy use. However, detailed analysis of the importance of different sources of market failure has not so far been undertaken. Chapter 5 describes the scope for empirical assessment of the practical significance of the various possible sources of market failure, suggesting directions of research, some of which are pursued in the second part of the report.

5. In Part 2 we use cross-sectional data from the 1986 English House Condition Survey (EHCS) to assess the role of economic factors in contributing to the pattern of household take-up of energy efficiency measures. Given the available data, which relate only to a single year, we develop a model of the pattern of possession (or, loosely, ownership) of certain energy efficiency measures, assessing the factors which increase or decrease the probability that a household will possess each measure. It is clear that economic factors alone will only explain part of what is a complex household decision process, and the analysis of this report should be seen as complementary to studies of other aspects of household decision-making, including both engineering evidence and attitudinal surveys.

6. Given the probable complexity of the relationships between socio-economic factors and energy efficiency investments, it is not possible to examine these influences on the basis of variable-by-variable cross-tabulations of the association between the pattern of take-up and economic variables. We use an econometric model to test empirically the effect of some of the hypotheses concerning economic influences, such as tenure and income, in an attempt to isolate those that have a strong effect on the take-up of energy efficiency investments. We develop a model to describe the factors that affect the probability that a specific household will have an insulation measure based on our knowledge of the annual fuel consumption by the household, the physical characteristics of the house, and the socio-economic characteristics of the existing occupant. We then estimate this model for three different types of insulation: loft insulation, wall insulation, and double glazing.

7. Our results appear to be consistent with the view that there are certain areas in which market failures may deter households from making rational decisions regarding energy efficiency investments, and they also give an indication of the magnitude of these effects. Policy initiatives which could be effectively targeted towards the reduction of these market failures would be expected to lead to an efficient increase in the level of insulation in domestic dwellings.

2. Domestic Conservation Decisions

8. The main focus of the report is on the actions households can take to prevent energy loss from existing energy-using activities, principally domestic space and water heating. The range of possible measures includes the installation of loft insulation, cavity wall insulation, double glazing, draught proofing, and the lagging of hot water tanks. In each case, the measures have the character of investments: money spent on them in one year yields benefits over a number of subsequent years.

9. In addition, although we do not consider them in detail in this report, there are certain other actions to reduce energy use that can be taken. Existing energy-using capital equipment may be replaced with new, more thermally efficient, equipment. As with insulation measures, the decision has the character of an investment decision, in this case complicated by the scrapping of earlier equipment. Changes in behaviour patterns may also reduce energy needs. These may range from the trivial, such as minor adjustments to lighting levels or ambient temperatures, to major rescheduling of domestic and business activity, such as changes in working hours to maximise the use of daylight.

10. The demand both for energy and for conservation investments is a derived demand (Barnett, 1986): consumers seek energy services, in the forms of heat, light, or power, from a combination of energy inputs (electricity, gas, etc.) and capital investments (appliances, insulation, etc.). The same situation applies to certain other products, such as building materials or domestic appliances. Thus, for example, the demand for building materials is for the building structures they can be made into, and ultimately for the services (shelter, etc.) that these structures provide.

11. The cost to a particular household of obtaining any given level of energy services is thus given by the price of energy inputs and by the efficiency with which these are converted into energy services. Energy efficiency measures are thus substitutes for the supply of energy. A reduction in the price of energy inputs, or an increase in energy efficiency, will both reduce the cost of energy services. Indeed, we can see that there is likely to be a close parallel between changes in energy efficiency and changes in the price of energy inputs. A reduction in the energy price would be expected to reduce the cost of achieving any given level of energy services, but spending on energy inputs by any particular household would be unlikely to fall by this amount. Some of the benefit to households of a lower price for energy inputs would be likely to be taken in the form of increased consumption of energy services (and the purchase of larger quantities of energy inputs); depending on the price elasticity of demand for energy services, expenditure on energy inputs used could fall, rise, or remain unchanged.

12. Similar effects should be expected from a change in energy efficiency: if energy efficiency rises, the cost of achieving any given standard of energy services will fall, and households may choose to consume more. Use of energy inputs may fall, but is unlikely to fall by as much as would be the case if the level of energy services used remained constant. A guide to the likely balance between the effect of greater energy efficiency on the quantity of energy inputs used and on the standard of energy services consumed is given by the price elasticity of demand for energy; the lower this is, the more likely it is that improvements in energy efficiency will result in reductions in the demand for energy inputs.

3. Calculation of Cost Effectiveness in Energy Efficiency Investments

13. Technical measurements of the housing stock, and of the impact that various energy efficiency measures would have on the energy inputs required to maintain current levels of heating etc., have formed the basis for a number of studies of the scope for energy savings through domestic energy efficiency measures (e.g. Pezzey, 1984; Henderson and Shorrock, 1989b). Broadly speaking, these studies have been concerned with two different types of estimate of the scope for energy savings. Firstly, technical measurements alone have been used to estimate the energy savings that could be achieved, if all *technically feasible* energy efficiency measures were implemented. Secondly, technical measurements and cost data have been combined, along with assumptions about the appropriate investment decision rule, to estimate the scope for energy savings through *cost-effective* energy efficiency measures. These measures are the subset of technically feasible measures which would contribute worthwhile (profitable) investments, given specific assumptions about the cost of the investment and the future course of energy prices.

Table 3.1
Possession of Energy Efficiency Measures (1989)

Measure	Country as a whole		Local authority tenants	
	Partial	Full	Partial	Full
Loft insulation	89%	44%	90%	32%
Draught proofing	37%	10%	38%	10%
Cavity wall insulation		22%		18%
Double glazing	47%	19%	15%	5%
Tank insulation	95%	11%	91%	9%
Central heating		78%		70%

Note: The figures are calculated as the percentage of the housing stock in which it would be possible to install the specific energy efficiency measure.

Source: Henderson and Shorrock, 1989a.

14. The estimates of the scope for energy savings through cost-effective energy efficiency investments, in particular, provide a useful yardstick by which to assess the extent of actual take-up of energy efficiency measures (Table 3.1). To the extent that the various assumptions made in the calculation of cost effectiveness are appropriate, and actual take-up of energy efficiency investment falls short of full take-up of all cost-effective measures, obvious questions are raised about the efficiency of household decision-making and the possibility of market failures in the market for conservation products.

15. In this chapter, therefore, we examine the basis for the estimates of the scope for cost-effective energy efficiency investments in the UK housing stock, and consider to what extent the apparent discrepancy between the estimated 'cost-effective' level of investment and actual investment take-up can be explained by features of the calculation of the cost-effective level, such as, for example, the omission of transaction costs. In the next chapter, we examine the market failures and other reasons that could explain why genuinely cost-effective measures have not been undertaken by individual households.

Methods of Calculation

16. The starting-point for the estimates of the scope for cost-effective energy efficiency measures is experimental measurement of the impact of each of the range of possible measures on the energy inputs required to maintain room temperatures, water temperature, and other services provided by energy at given levels. Clearly, the impact of energy efficiency measures will be a function of characteristics of the property and of the baseline pattern of energy use; in addition, the impact of one measure is unlikely to be independent of what other measures have been adopted. The extent of technically feasible savings can thus be calculated for a typical property, or, making assumptions about how the potential for energy savings is related to the characteristics of individual properties, for a representative sample of properties such as those surveyed by the English House Condition Survey.

17. Further assumptions are then required to identify cost-effective energy-saving investments - costs for the investment, prices for energy (to value the future energy savings), and an appropriate decision rule to weigh up costs and benefits in different time periods. The issues involved in the choice of an investment decision rule are familiar, and in practice the net present value rule has been generally accepted in most calculations of cost effectiveness. This discounts future costs and benefits by a predetermined discount rate, to yield a figure for the present value of the future net benefits from the investment, which can be compared with the initial investment outlay. The net present value of the investment is thus given by

$$NPV_0 = -C_0 + \sum_{t=1}^{N} S_t \frac{P_t}{(1+r)^t} \tag{3.1}$$

where S is the reduction per period in the amount of energy required to provide the current level of energy services, P is the expected real price of energy in each period, C_0 is the initial outlay, r is the discount rate, and N is the decision-maker's planning horizon or the lifetime of the investment.

18. Whilst in principle the NPV criterion should be followed to select all investments with positive net present value, a measure of the 'degree' of cost effectiveness of each different investment can be obtained by dividing the net present value by the initial capital cost, giving the net present value per unit of capital cost, *NPV/K*.

19. Illustrations of the cost effectiveness of a range of energy efficiency investments in a typical private dwelling, based on calculations in Pezzey (1984), are shown in Table 3.2. It is clear that there are large differences in the cost effectiveness per unit of capital of the various energy efficiency investments shown, ranging from large gains per unit of investment from insulation of the hot water tank, to small net losses from the installation of double glazing.

20. The gains are sensitive to the type of fuel used for heating and the heating standard at which the dwellings are maintained. As the table displays, savings are generally greater where electric heating is used than where heating is by gas. The heating standard is divided into well-heated (WH) and poorly-heated (PH) homes (see Pezzey (1984)). The well-heated homes are assumed to maintain a downstairs temperature of 19°C and an upstairs temperature of 16.5°C during the

Table 3.2

Net Present Value per Unit of Capital Cost for Various Energy Efficiency Measures

Type of insulation	*NPV/K*			
	Gas heating		Electric heating	
	WH	PH	WH	PH
Loft insulation - an increase from 0 to 100mm	4.6	1.4	8.6	5.3
Wall cavity insulation	2.3	1.2	4.6	4.8
Double glazing				
Entire house	-0.6	-0.7	-0.4	-0.4
Downstairs only	-0.5		-0.2	
Draught proofing - a reduction of the ventilation rate by 25%*	0.0	0.3	0.7	2.4
Hot water tank insulation	16.0		51.0	

WH = well-heated homes; PH = poorly-heated homes.

* This reduction in ventilation rate can be achieved through the weather-stripping of all windows, external doors, and loft hatch, the blocking of airpaths around pipes, and the sealing of wall-floor and wall-ceiling joints.

Source: Derived from estimates in Pezzey (1984).

cold season. Poorly-heated homes are assumed to maintain an average downstairs temperature of 16°C (which is roughly equivalent to the mean downstairs temperature if a single downstairs room is heated to 19°C whilst all other downstairs rooms are not heated) and no heating upstairs. This classification of heating standards can be broadly compared with the ownership of central heating, as the heating of an individual room described for the poorly-heated house can be seen as comparable with the use of individual room space heaters, and the heating of all of the rooms in the dwelling is consistent with the use of a central heating system. Hence, the figures in Table 3.2 signify a generally higher level of savings for dwellings with central heating than for those without.

21. How appropriate are the assumptions made in calculating the net present value of different energy efficiency measures as a measure of the full set of costs and benefits which an individual decision-maker would wish to take into account? We consider each of the elements of the net present value calculation in turn.

(i) Initial cost

22. Calculations of the cost effectiveness of energy efficiency investments which include within the initial outlay only the 'purchased' items - materials and contractors' services - will omit two important sources of cost, which may be perceived, quite reasonably, by households as reasons not to undertake certain investments.

23. The first group of omitted costs are costs of inconvenience and incidental damage that households may experience in having certain types of energy efficiency measure installed - the loss of amenity during installation and the costs of 'making good' incidental damage caused, including any re-wallpapering, repainting, and cleaning that may be necessary.

24. Secondly, most measurements of cost do not take into account the DIY costs of labour. This is justified by Pezzey (1984) on the grounds that it is very difficult to measure the cost to an individual of the time and trouble involved in DIY projects. Of course, some may gain utility from installing the measures themselves. Others will find the task so onerous that no amount of savings will convince them that it is a good idea. However, although the spectrum of costs ranges widely, this is no reason for such costs to be ignored. The conventional method of dealing with a problem such as this is to use an opportunity cost method of costing labour time. This could be either applied to an average wage rate or the cost of hiring a contractor to do the work. Pezzey uses both DIY figures exclusive of labour costs and contractors' costs figures to calculate *NPV/K*. The calculations for contractors' costs are used here, as they incorporate both the hiring of a contractor and one possible method of applying an opportunity cost to DIY estimates.

25. It should, however, be noted that even where a contractor is in fact employed there may also be some 'DIY' time costs to the individual; hiring a contractor to undertake work still requires the householder to bear the 'hassle' costs of co-ordination and supervision, which may vary considerably from case to case. Additional transaction costs are the costs of firming up what work is needed, how it should be done, and selecting the contractor.

(ii) Future reductions in energy use

26. The calculation of the impact of any given energy efficiency measure on future energy use, assuming a constant level of energy services, requires the application of complex physical data and relationships, derived in laboratory conditions, to actual situations. In practice, the calculations cannot possibly take into account all of the precise house-specific physical and socio-economic factors that will affect the level of energy required to achieve a given standard of energy services. These include whether the house has central heating, the material that the house is made of, and the extent of existing energy conservation measures. Considerable further disaggregated research is needed, based on detailed analysis of different physical and socio-economic factors.

27. Most energy-saving investments display diminishing returns. For example, the rate of return to each additional centimetre of loft insulation decreases quite sharply. Figures from Pezzey (1984) show that the net present value of investment in loft insulation per unit of capital (*NPV/K*) is equal to £8.60 when insulation is increased from zero to 100mm, but if there is already 25mm of insulation, adding 100mm will yield an *NPV/K* of £2.40, and if there is already 50mm, the *NPV/K* is only £0.80.[1]

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[1] These figures assume electricity-powered centrally heated homes.

28. Some measures also have diminishing returns with respect to an increase in the uptake of *other* energy efficiency goods; the net present value of one measure is affected by what other measures are also taken. Some measures are complementary, increasing the level of energy savings when combined, whilst others detract from each other's effectiveness, causing the level of energy savings to decrease with the uptake of another measure. An example where measures are complementary is wall insulation combined with loft insulation in a house that does not heat the upstairs. The measure that is applied first will increase the heating level upstairs and cause more energy savings attributable to the second measure than that measure would cause alone. An example where two investments detract from each other would be the combination of loft insulation and a more efficient heating system. The new heating system will lower the amount of savings from loft insulation, as less heat is able to escape from the boiler which lowers the level of heat in the house and reduces the savings from loft insulation.

29. In addition, whether a measure is cost-effective in a particular application will also depend on the characteristics of the particular household's consumption of energy services. A household with more members or whose members are home for more of the day will, other things being equal, tend to have higher energy demands, as will households with higher incomes and households whose members have a preference for warmer ambient temperatures etc. These households will then tend to be able to make greater savings from the installation of energy efficiency measures than those with lower energy demands, and more measures will appear to them to be cost-effective.

30. Finally, these calculations assume that the level of energy services consumed is kept constant and households take all of the benefits in the form of monetary savings from reduced fuel use. In practice, this assumption is unlikely to be accurate. Many households will increase their consumption of energy services, and hence the monetary savings will not be as great as the *NPV/K* method suggests.[2] Of course, the household's utility level will increase with the greater consumption of energy services, and in theory should be higher than if all benefits had been taken in the form of reduced energy consumption.[3] Nevertheless, benefits in terms of increased comfort etc. may not appear to the household in the same manner as lower utility bills and may in practice be treated differently in any assessment of overall benefits.

(iii) Future energy prices

31. The issue of the price of energy is contentious, as it is not easy to forecast future energy prices, which in turn affect the level of savings attainable by the investment. The calculations made by Pezzey (1984) quote two values for the *NPV/K* figure of each investment, one assuming no increase in real fuel prices and the other assuming a 3 per cent real increase. The estimates reported above are based on the first of these assumptions. Recent events display how difficult it is to make these assumptions, and they should be considered to have quite a large margin of error. The possibility of a sustained low level of energy prices for a period of many years cannot for example be ruled out, and would have major implications for the cost effectiveness of energy efficiency measures.

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[2] In an examination by the Social Policy Research Unit of a low-income target scheme of energy conservation, only 21 per cent of the residents in the scheme actually reduced expenditure on energy with the uptake of the insulation measures. 70 per cent spent exactly the same amount on delivered energy, hence increasing their consumption of energy services, and 9 per cent increased their expenditure (Hutton et al., 1985).

[3] On the basis of a revealed preference argument.

32. Uncertainty about the rate of return on energy efficiency investment, due to uncertainty about future energy prices, could lead to households requiring a higher rate of return, or some 'risk premium', before they were prepared to undertake the investment. This, too, is typically not reflected in the calculation of 'cost effectiveness'.

(iv) Discount rate

33. The final area for consideration is the discount rate. The conventional discount rate used is a real rate of 5 per cent, which indicates a willingness to postpone benefits from this period to next period so long as they increase at the rate of 5 per cent. This assumption has received much criticism from some economists, who claim that the individual discount rate is actually much higher than the social discount rate, as individuals are more myopic than policy-makers. (Note that it can be equally argued that politicians, who rarely spend more than a decade in office, may be more concerned with short-run pay-offs than the long run, while heads of families may be concerned about a much longer period of time, possibly including future generations.) Hausman (1979) calculates an average individual discount rate of 26.4 per cent, which varies inversely with income. A higher discount rate implies that a shorter payback period is necessary for investments.

4. Sources of Market Failure in Energy Efficiency

34. The calculations described in the previous chapter demonstrate the potential for reducing domestic energy use through investments in energy-saving measures, and they also show the extent to which households have failed to invest in energy efficiency measures which would appear to be cost-effective for them to undertake. The calculations do not, however, reveal *why* particular households have failed to make cost-effective energy-saving investments, and therefore provide only limited guidance as to the form of any public policy interventions to improve take-up. Understanding why the decentralised market system fails to lead to apparently beneficial outcomes - in other words, identifying the sources of market failure - is an essential preliminary to devising forms of intervention targeted at the underlying problems and most likely to improve matters without excessive cost.

35. In this chapter we attempt to set out the various forms of market failure which could account for incomplete take-up of potentially beneficial investments in energy efficiency.[4] Broadly speaking, the relevant market failures can be analysed under four headings.

(a) Information

36. Some consumers may fail to undertake cost-effective measures because they are poorly informed about the technological possibilities for energy efficiency investments and about the likely impact of such investments on their fuel use and costs. This general statement has a number of separate aspects.

37. The first may simply be the adequate dissemination of existing information about the general properties of the various possible measures and their impact on the thermal efficiency of dwellings in general. Some of this information may be technical and not easily communicated to the layperson. However, in general, this aspect of informational market failures is perhaps the most likely to be resolved through the efforts of market participants; suppliers have an obvious self-interest in advertising and communicating information as long as the gains from greater information exceed the dissemination costs.

38. A second aspect of the information problem is that to make appropriate decisions, consumers need not merely general information about the properties of energy efficiency measures in 'typical' applications or laboratory conditions, but also specific information enabling them to assess the cost effectiveness of such measures in their own individual circumstances. The gains from undertaking energy efficiency investments will depend on the physical characteristics of the property and the pattern of individual energy use, and precise calculations of the likely gains will be complex and normally beyond the capability of individual householders.

39. A third, and more intractable, information problem is that the asymmetry of information between buyers and sellers of appliances and insulation materials could give rise to adverse selection in the range of appliances and materials on offer. Purchases of energy efficiency goods are in general one-off transactions, and consumers therefore do not gain experience of the various competing products on offer through repeated purchase. If this means that consumers are unable to make an adequate assessment of the merits of competing products before purchase, and if the production of fuel-efficient goods is more expensive than the production of fuel-inefficient goods, the competitive process is likely to tend to drive out fuel-efficient products from the range offered by the market. The additional expense involved in manufacturing such products will not be

[4] See also on this Jochem and Gruber (1990).

warranted by the additional sales that can be achieved by improving fuel efficiency, since consumers are insufficiently aware of the relative merits of different products to identify and choose those resulting in the greatest gains in energy efficiency.

40. The implications of this process are rather more general than the incomplete take-up of apparently beneficial energy efficiency measures - although fears about encountering 'cowboy' contractors are likely to be part of the story behind incomplete take-up. It is possible that, beyond this, the asymmetry between buyers and sellers could result in an inadequate pace of development of the fuel efficiency characteristics of goods; if consumers are unlikely to be able to value improvements in fuel efficiency properly, firms will devote inadequate resources to research and development to extend and improve the range of available energy efficiency measures. The adverse selection problem could thus affect the scale of cost-effective measures, as well as the extent to which they are taken up.

(b) Non-Optimisation

41. Even if consumers are fully informed about the potential benefits from energy efficiency investments, they may fail to make appropriate decisions based on the information they possess.

42. One aspect of this may be that consumers may use 'inappropriate' decision rules for weighing up costs and benefits in different time periods. The estimates of the cost effectiveness of energy-saving investments discussed in the previous chapter use the net present value of the investment as a criterion for identifying worthwhile projects. Alternative decision rules, including some widely used in commercial investment appraisal, could lead to different judgements about cost effectiveness. Thus, for example, use of the 'payback period' of an investment (i.e. the period of time before the costs of an investment are recovered) will tend to select projects where the benefits are obtained rapidly and will tend to reject projects where a substantial part of the benefits lie in the distant future. If the net present value is taken as the correct decision rule - as it normally should be - then consumers who use other rules will assess cost effectiveness incorrectly, and may thus fail to make optimal decisions.

43. A more general problem of non-optimisation is that consumers may simply behave in ways that do not conform to the 'utility-maximising' model of behaviour underlying standard economic analysis. Of course, many of the reasons why consumers may behave like this can be interpreted in terms of costs omitted from the cost-effectiveness analysis; a consumer who 'cannot be bothered' to appraise alternative investments correctly may be interpreted as a consumer who optimises, subject to large fixed costs in investment evaluations.

(c) Non-Appropriability of Benefits

44. Cost-effective investments may not be undertaken if the person who benefits from energy efficiency improvements is not the person paying for them. This includes problems in tenanted housing, where the tenant may bear responsibility for paying energy bills, but where the landlord may be responsible for making any capital investments and improvements which would reduce energy use. Thus, for example, 92 per cent of owner-occupiers with accessible lofts have loft insulation but the proportion amongst tenants of private landlords is only 62 per cent (Henderson and Shorrock, 1989a). In principle, landlord and tenant could bargain to ensure that an optimal level of energy-saving measures was installed; tenants could make payments either specifically, or in the form of higher rents, to induce their landlord to invest in energy saving on their behalf. However, there are obvious problems with this where the improvements would benefit a number of different tenants, as, for example, in multi-occupied tenanted houses or where a succession of short-stay tenants are involved. In the case of multi-occupancy the difficulties are the

'free-rider' incentives relating to the financing of the public good (tenant-financed energy saving); with short-stay tenants, some beneficiaries will be future tenants, who cannot conceivably participate in any bargain.[5]

45. Non-appropriability of the benefits from energy-saving investment may also be a problem where properties are owner-occupied.[6] Owner-occupiers who invest in energy-saving measures may be unable to reap the full benefits from their investment if they choose in future to sell the property, and if the benefits are not fully capitalised into the price because the future purchasers of their property cannot accurately assess the worth of past fuel efficiency measures. Again, the problem can ultimately be resolved to one of information asymmetry; sellers may be better informed about the value of double glazing or loft insulation than the potential purchasers of their property.

(d) Credit Market Failure

46. To what extent should poverty be regarded as a source of market failure in energy efficiency investment? A number of studies have alluded to the lower level of such investments amongst poorer households,[7] but it is not clear whether poverty as such, or other characteristics of the household (such as low energy use or tenure), should be seen as the underlying reason for low take-up. From a theoretical point of view, indeed, the level of current household income should not be a factor affecting the value of energy efficiency measures; these have the character of investments, and an investment with a positive net present value is in principle worthwhile undertaking, regardless of the level of current household income. If current household income is insufficient to cover the costs of the investment, it will be worthwhile to borrow to finance the investment, so long as the real interest rate on loan finance does not exceed the internal rate of return on the investment.

47. On the other hand, the 'investment' nature of the installation of energy-saving measures gives rise to scope for take-up of energy-saving measures to be affected by market failures in the market for credit. Either energy-saving investment requires current consumption to be forgone, in order to obtain future energy savings, or it requires loan finance to be undertaken. Certain groups of the population, especially those with limited collateral, may be severely restricted in their access to credit at the market rate of interest.[8] These problems may manifest themselves as a requirement for a high - possibly infinite - discount rate, depending on whether the lack of credit has already affected the time profile of individual consumption.

48. Nevertheless, problems of credit market failure can be overstated. In the case of energy efficiency investments, the capital outlays required are, in many cases, small. Moreover, availability of credit would appear to be a problem for only a few groups of the population; if anything, current experience seems to suggest that banks have been prepared to extend credit at normal interest rates well beyond the point at which individual borrowing levels are prudent and sustainable.

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[5] Except where rent-control legislation permits this by paying higher rents, once the energy-saving measures are installed. The scope for this is, again, likely to be limited where potential future tenants lack information about the energy efficiency and/or energy consumption level of the dwelling.

[6] See Laquatra (1986) and Horowitz and Haeri (1990) for a discussion of the capitalisation of energy efficiency measures in house prices.

[7] See, for example, Boardman (1991).

[8] Microeconomic studies (e.g. Weber, 1990; Davies and Weber, 1991) which use data on the level and pattern of household expenditures to assess the importance of liquidity constraints suggest that certain groups of the population may be restricted in their access to credit at the market rate of interest.

5. Issues for Research

49. The preceding discussion has sought to clarify the nature of the estimates of 'cost-effective' energy efficiency measures in domestic dwellings and the various potential sources of market failure that might prevent households undertaking measures that were genuinely to their advantage. The practical significance of the various possible explanations for the pattern of take-up of energy efficiency measures is, however, unresolved by this discussion, which can merely indicate the range of possibilities. In the second part of this report, we use micro-data from the English House Condition Survey on the possession of energy efficiency measures to examine individual decisions and to seek to identify the significance of the various possible sources of market failure.

50. One set of hypotheses to be examined concerns the nature of the individual decision-making process. The model of cost-effective energy efficiency investment set out above is one in which the pattern of investment would be determined by the extent of individual households' costs and benefits from energy efficiency investments. Within this framework, those households which would be most likely to install energy efficiency measures would be those for which the gains in terms of reduced energy bills and/or greater comfort would be greatest. Whilst some of the elements of the calculation of cost efficiency are likely to be common across households (e.g. future energy prices), differences in the cost of energy efficiency measures to individual dwellings (reflecting differences in the physical structure of different dwellings) and differences in the level of individual households' energy consumption would give rise to differences in the potential savings to be made from energy efficiency, which would presumably then be reflected in differences in ownership decisions. The EHCS gives information on both the physical characteristics of the dwelling and fuel consumption data, which may indicate differences in potential energy savings amongst households.

51. Following on from hypotheses concerning the appropriateness of the basic behavioural model, it will then be possible to explore a range of hypotheses concerning the market failures discussed in Chapter 4 - information, non-optimisation, non-appropriability, and credit market failures. Market failures of the first two sorts cannot readily be observed with the available data, although aspects of these market failures may be reflected in a failure of the estimated models to conform to patterns that would be expected from the underlying investment model - especially the relationship between household energy demands and take-up noted above.

52. Market failures due to difficulties in appropriating the benefits of energy efficiency investments would be revealed by a lower propensity to undertake these investments amongst tenants and amongst owner-occupiers in the categories and age-groups most likely to want to move and to sell the house in which the investments have been made. The mere existence of differences in the overall level of take-up between such households and others is not conclusive evidence of market failures; housing tenure may also be correlated with household energy use, and may have an influence on the level of energy efficiency devices through this channel. However, it should be possible to distinguish the effects of tenure, incomes, and other factors influencing energy demands and hence energy efficiency investment from other influences of housing tenure on energy efficiency investment that could reflect market failure due to the non-appropriability of benefits.

53. Credit market failures are difficult to observe, but may be indicated if non-take-up is correlated with certain characteristics of the household likely to be correlated with credit restrictions - unemployment and low incomes, especially. A more general relationship between income and take-up would not, however, be expected and would be inconsistent with the 'investment' nature of the decision.

6. The Data

54. The research reported here uses data from the 1986 English House Condition Survey. The key features of the English House Condition Survey, which make it particularly suited to economic modelling of energy saving, are the combined availability of data on the physical characteristics of each property and socio-economic data on the current occupants.

55. The survey contains a wide range of information about the accommodation and other characteristics of a sample of nearly 7,000 households in England, including specific physical features of the dwelling such as area, type of structure, location, method of space and water heating, and the types of fuel used, as well as information on the existence of loft insulation, wall insulation, double glazing, draught proofing, and water tank insulation. The survey also includes some information on socio-economic factors such as the combined income of the two heads of household, the composition of the household, the employment status of the head of household, the type of tenure (owner-occupied, private rented, council rented, etc.), how long the current occupants have lived in the dwelling, and their expectations regarding possible future moves. A sub-sample of the data is accompanied by fuel consumption information from both gas and electricity board records.

Table 6.1
Characteristics of the Full Data Sample
(6,408 households from 1986 EHCS)

		% of sample in tenure group			
Income decile	**Average annual income (£)**	**Owner-occupier**	**Local authority / housing association tenant**	**Private tenant**	**Average area (sq. m.)**
1	1,500	34	49	17	91
2	2,104	34	54	12	94
3	2,853	36	51	13	95
4	3,770	44	45	11	103
5	5,170	53	36	11	107
6	6,880	64	27	9	102
7	8,186	72	20	8	115
8	9,432	81	13	6	114
9	11,335	86	9	5	133
10	16,129	93	3	4	153
Total	6,735	60	30	10	111

56. Most of the variables in the EHCS have a straightforward interpretation, and correspond closely to variables used in models of household decision-making based on the Family Expenditure Survey (FES) or other widely-used micro-data sources. However, the income variable used in this analysis requires some discussion. The EHCS collects income data only from the two principal adults in each household, rather than from all adult household members as in the FES, and the total household income observed in the EHCS will thus differ from the

total household income that would be recorded in the FES. Although this reduces the comparability of the income data, in many cases it will cause no problems for the analysis of this report, since the EHCS definition may in practice identify the relevant group on whose incomes household decisions would be based. Other household members may not consider the home a permanent residence, and may have little or no interest in energy efficiency investments. However, this will not always be the case, and where it is not, the appropriate level of household income will have been measured with error.

57. A further feature of the EHCS income data is that no information on income from savings is collected or imputed. As a result, the data on household income which are used in this analysis will differ from true household income by an amount that will vary, without being entirely random. The omitted income will tend to be greater for older households, and for households with higher incomes. More generally, it should be observed that use of information on current incomes as an indicator of household living standards ignores the use of saving as a means by which households can maintain a time profile of consumption which differs from that of current incomes. If data on aggregate household expenditures on goods and services were available this might be a better indicator of these households' living standards than is current income (Blundell and Preston, 1991), but such data are not collected in the EHCS. Instead it is necessary to bear in mind that income will not always be an accurate indicator of living standards, and that the bottom decile of incomes in particular will contain some households with higher living standards.

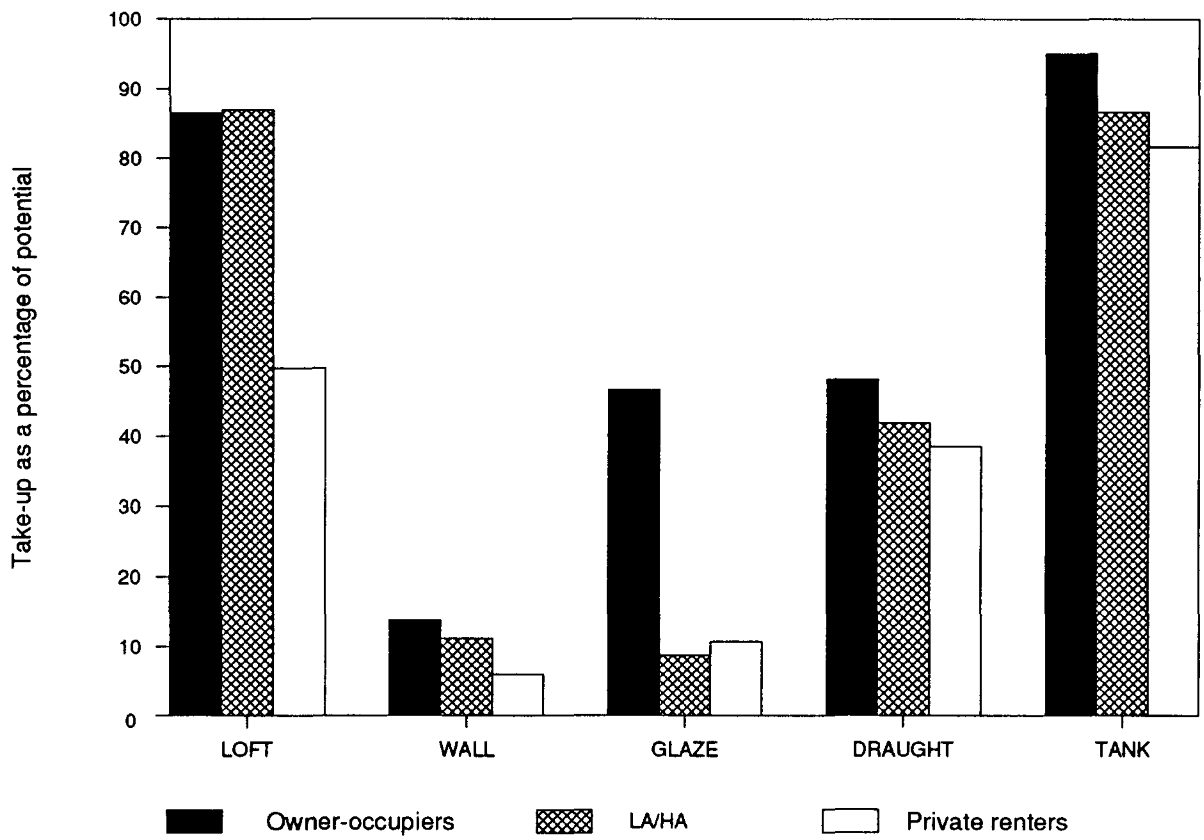
Table 6.2
Characteristics of the Consumption Sub-sample
(1,294 households from 1986 EHCS)

		% of sample in tenure group				
Income decile	Average annual income (£)	Owner-occupier	Local authority / housing association tenant	Private tenant	Average area (sq. m.)	Average fuel consumption* (therms)
1	1,635	49	39	12	103	536
2	2,558	59	32	9	96	581
3	3,574	62	37	1	112	695
4	5,092	68	31	1	106	657
5	6,863	71	23	6	101	678
6	7,661	82	15	3	106	718
7	8,929	91	8	1	107	809
8	10,397	92	8	0	112	802
9	12,014	95	3	2	123	837
10	17,100	96	3	1	145	1,030
Total	7,623	77	20	3	111	734

* These figures are based on the fuel consumption sub-sample.

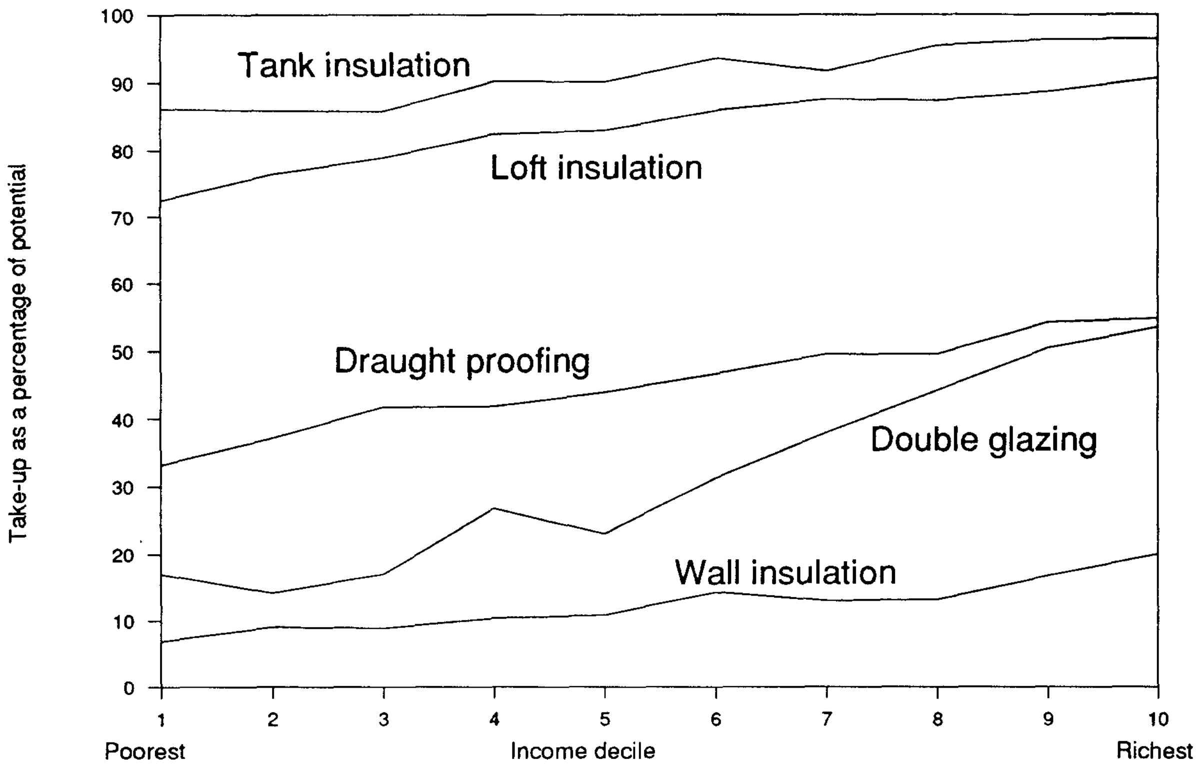
58. In some of the analysis described in this report we have made use of models including information about household fuel consumption, and the sample size in these parts of the analysis (just under 1,300 households) is considerably less than in the analyses for which consumption information is not required. The reason for this is partly that only a sub-sample of the EHCS data is accompanied by fuel consumption information from both gas and electricity boards, but also that we have restricted the analysis of consumption to those households using mains gas as the main heating fuel. This is because it is not possible to devise a fully satisfactory aggregate of gas and electricity consumption for use in a behavioural model, given that the unit prices of gas and electricity differ. Aggregating gas and electricity on the basis either of energy quantities or of energy expenditures would ignore the fact that the prices of gas and electricity differ, and the difference in prices could lead gas-consuming and electricity-consuming households to make different insulation choices, for a given energy consumption. We have also reduced this sub-sample further by omitting dwellings that are not amenable to any of the insulation measures (dwellings with no loft, for example). The characteristics of the sub-sample are broadly similar to the entire sample, but do have a slightly higher mean income and a higher proportion of owner-occupiers. As Table 6.2 shows, the mean annual income of the sub-sample is £7,623 compared with £6,735 for the entire sample. The proportion of the sub-sample that are owner-occupiers is 77 per cent compared with 60 per cent for the entire sample.

Figure 6.1
The Ownership of Insulation Measures by Tenure
(1986 EHCS)



59. Figure 6.1 shows the ownership of the five main energy efficiency measures by tenure sub-category. It is clear that the data support the hypotheses that renting tenants have a lower ownership rate than owner-occupiers, and that renters from local authorities or housing associations have a higher percentage of ownership (with the exception of double glazing) than tenants in the private rental sector.

Figure 6.2
The Ownership of Insulation Measures by Income Decile
(1986 EHCS)



60. The possession of insulation measures by income decile is plotted in Figure 6.2 for each of the investments. Whilst there is a slight upward trend for most of the measures, the difference is not much more than 10 percentage points between the poorest tenth of the sample and the richest tenth. Double glazing is a clear exception and, as can be seen in both Figure 6.1 and Figure 6.2, it does not seem to follow the same pattern of ownership as other pure insulation measures. This may be because double glazing is more frequently installed for reasons other than energy efficiency, which would suggest that in the subsequent analysis the form of the appropriate economic model may be different.

61. The two figures suggest that tenure has a considerable impact on the ownership of energy efficiency measures, whilst (except in the case of double glazing) income has a much smaller effect. However, we cannot deduce that a causal relationship exists between tenure and energy efficiency investments, based on the evidence of these graphs. There are several other factors that may affect the observed correlation between energy efficiency measures and tenure, such as size and age of the dwelling and employment status of the head of the household, and the contribution of these needs to be disentangled from the observed correlation to identify the separate contribution of tenure.

7. The Model

(a) The Theoretical Model

62. In Chapter 3 we argued that, in the absence of market failures, the decision to take up energy efficiency investments should purely be a function of the net present value of the investment. Socio-economic factors would not be expected to influence the decision to invest in domestic insulation, so long as domestic insulation has a positive return, evaluated at the appropriate rate of discount. Whether in practice socio-economic factors do affect insulation decisions is one of the aspects of household behaviour which this study aims to explore.

63. To begin with, we set out a simplified formal model of the way in which various relevant factors would be expected to influence the probability that an individual household would possess energy efficiency measures. The purpose of this model is not to provide a detailed representation of individual decision-making processes, but rather to identify the *way* in which certain key influences would be expected to affect household decisions about energy efficiency. The model will then be used as an aid to interpretation of the results of the statistical estimates described in later chapters.

64. The model is one in which households are assumed to make current decisions about the level of fuel consumption, and about the level of domestic insulation, in a single time period. This is, of course, a major simplification of the actual position of many households in the data sample, who may already be in possession of energy efficiency measures that they would not necessarily choose to install, if they were making the decision in current circumstances. However, representing the decisions in this way simplifies the formal model considerably, by allowing us to focus on the choices made by households which are actively choosing between energy efficiency and fuel expenditures. The single-period representation also allows us to abstract from the complexities involved in forecasting future energy prices and energy needs.

65. We begin by noting that what households seek is neither a certain level of energy expenditure or consumption, nor energy efficiency devices as ends in themselves. Rather the benefits to individual households of energy consumption and energy efficiency investments are the contributions they make to an underlying good, which we characterise as 'warmth'.

66. We define a utility function, where utility (U) is a function of warmth (W) and all other goods (x),

$$U = u(W,x) \tag{7.1}$$

67. The scope for households to achieve different levels of warmth is represented by the following 'production function' for warmth:

$$W = f(C,I,e) \tag{7.2}$$

where W = warmth,
C = consumption of domestic fuel,
I = the level of insulation, and
e = efficiency of heating equipment.

In what follows, we simplify matters by ignoring the role of appliance efficiency, although in practice it may be an important factor.

68. Assuming all households are utility maximisers, the first-order condition for utility maximisation is

$$\frac{\delta U}{\delta x_i} = p_i \tag{7.3}$$

which, in the context of our model, yields

$$\frac{\delta U}{\delta C} / \frac{\delta U}{\delta I} = \frac{p_C}{p_I}. \tag{7.4}$$

69. The chain rule and other algebraic manipulation gives the following expression, which relates the marginal rate of substitution between insulation (*I*) and fuel consumption (*C*) to the ratio of the prices of insulation and fuel:

$$\frac{\delta I}{\delta C} = \frac{p_C}{p_I}. \tag{7.5}$$

70. The level of insulation chosen by a particular household will thus be a function of the household's consumption of fuel and of the relative prices of fuel and insulation. So long as neither insulation nor fuel consumption is desired in itself, but only as a means to attain a desired level of warmth, we would not expect preferences between warmth and other goods to enter into the insulation function. For a given level of warmth, the amount of insulation chosen would be related only to the level of fuel consumption chosen and to the relative prices of fuel and insulation. Thus

$$I = g\left(\frac{p_C}{p_I}, C\right). \tag{7.6}$$

71. Fuel consumption, in this model, will be a function of the chosen level of insulation and of a range of variables reflecting preferences for warmth, including, perhaps, income, various characteristics of the dwelling, and other characteristics of the household (number of members of different ages, patterns of work, etc.):

$$C = c(I, Y, D) \tag{7.7}$$

where Y = income and
D = other household characteristics.

72. The system of equations given by (7.6) and (7.7) describes the insulation decision as a function of fuel consumption and the fuel consumption decision as a function of insulation. The econometric problems that this endogeneity causes are discussed further in Section b below.

73. First, however, we consider the implications of relaxing some of the simplifications we made in setting up the model for the insulation decision, represented by equation (7.6). What reasons might there be for expecting other factors, beside the level of energy consumption and the relative prices of energy and insulation, to enter into the insulation decision?

74. Broadly speaking, there are three groups of reasons for other variables beside fuel consumption and relative prices to appear in an estimated model of the insulation decision. Firstly, the level of current fuel consumption may not be an adequate summary of the long-term level (and time profile) of fuel consumption that would be the relevant variable if we relax the single-period nature of the analysis. This may be because households currently making insulation decisions expect future changes in fuel consumption (for example, because they may expect to move house, in which case the consumption level that may be relevant for the decision is not their own consumption level but, perhaps, the average consumption level of the possible future

occupiers). Alternatively it may be because the insulation decision was taken earlier, perhaps by previous occupiers, and the relevant level of fuel consumption which entered the investment decision then would not have been the fuel consumption of the current occupiers of the property.

75. A second reason for other variables beside fuel consumption and relative prices to appear in an estimated model of the insulation decision is that the prices of fuel or of insulation may vary across households. This is particularly likely with insulation: although all households may face the same prices for insulation goods and materials, the price of a given standard of insulation will vary with the physical features of the property. The price of a given level of loft insulation will be higher for a house with a larger loft, for example. This will be a reason for expecting a considerable number of variables relating to the physical characteristics of the property to be encountered in an estimated insulation equation.

76. Finally, a third reason for other variables to appear in the insulation equation is that there are various types of market failure influencing the insulation decision. In particular, if economic and social variables such as income are encountered in the insulation equation, this may be due to their role as proxies for the various forms of possible market failure discussed in Chapter 4.

(b) The Econometric Model

77. Given our model derived above and assuming a linear (or log-linear) relationship, we have the two-equation system:

$$I_i = \alpha_1 + \beta_1 C_i + \beta_2 D_{1i} + u_{1i} \qquad (7.8)$$

$$C_i = \alpha_2 + \gamma_1 I_i + \gamma_2 D_i + u_{2i} \qquad (7.9)$$

where $D_i = [D_{1i} D_{2i}]$ is a vector of household characteristics, u_{1i} is a vector of unobservable influences that affect insulation ownership, and u_{2i} is a vector of unobservable influences that affect fuel consumption.

78. This system describes insulation as a function of fuel consumption and fuel consumption as a function of insulation. If this model is correctly specified, we may have endogeneity in the system, i.e. consumption is not independent of insulation ownership in (7.8) and insulation ownership is not independent of consumption in (7.9). This will pose a problem in the estimation of the ownership of insulation. One of the assumptions of the regression model is that the explanatory variables are exogenous, that is, they are autonomous of the dependent variable. If this is not the case, a separate regression analysis of these equations will not be able to disentangle the causal relationship and our estimates will suffer from a simultaneous equations bias. There are two possible methods of allowing for this simultaneity - estimation of a reduced form model or estimation of the structural model using techniques to deal with endogeneity.

(i) The reduced form

79. One method of estimating structural models is to avoid the endogeneity problem by estimating the reduced form of the system:

$$I_i = \alpha_3 + \delta_1 D_{1i} + \delta_2 D_{2i} + \upsilon_i \qquad (7.10)$$

where

$$\alpha_3 = \frac{\alpha_1 + \beta_1\alpha_2}{1 - \beta_1\gamma_1} \qquad \delta_2 = \frac{\beta_1\gamma_2}{1 - \beta_1\gamma_1}$$

$$\delta_1 = \frac{\beta_1\gamma_2 + \beta_2}{1 - \beta_1\gamma_1} \qquad \upsilon_i = \frac{\beta_1 u_{2i} + u_{1i}}{1 - \beta_1\gamma_1}.$$

80. This reduced form analysis yields consistent estimates of α_3, δ_1, and δ_2 provided that u_{1i} and u_{2i} are independent. This procedure does not estimate β_1, β_2, γ_1, or γ_2. Hence, the reduced form estimation cannot separate the effects of demographics on fuel consumption from those on insulation ownership and it cannot estimate the effect current consumption may have on the current ownership of insulation. If we expect these influences to be important, we may need to investigate the structural model.

(ii) The structural model

81. The estimation of simultaneous equations must address the endogeneity in the system. We wish to estimate (7.8), but we suspect that C_i is endogenous. This can be seen in (7.8) and (7.9). The error term of the ownership equation, u_{1i}, may be correlated with C_i because of the relationship between C_i and I_i in equation (7.9). Hence, our assumption of a random error term is violated.

82. We may obtain consistent estimates using a two-stage least squares (2SLS) technique of estimation which purges the reduced form consumption equation of any stochastic element that may be correlated with u_{1i}. Our system of equations is rewritten below, where consumption is written in its reduced form.

$$I_i = \alpha_1 + \beta_1 C_i + \beta_2 D_{1i} + u_{1i} \tag{7.8}$$

$$C_i = \alpha_2 + \gamma_3 D_i + u_{3i}. \tag{7.11}$$

83. Using the 2SLS procedure, we estimate the reduced form of the fuel consumption equation, (7.11), first and use the predicted values of this regression as C_i in the ownership equation. This procedure purges C_i of the stochastic element that is correlated with u_{1i} and leads to consistent estimates of the factors that influence the ownership of insulation net of those factors which influence fuel consumption. In order to identify the equation, this procedure requires at least one variable (instrument) to be included in the consumption equation which is not included in the insulation equation. The variable chosen for this purpose in the present analysis is the number of children at varying age levels in the household. We assume that this can affect fuel consumption, but that it will have no effect on the choice to install insulation except for any possible effect through its effect on fuel consumption. This procedure leads to consistent estimates when consumption is endogenous in the system.

84. Smith and Blundell (1986) have developed a method for the estimation of a simultaneous system with a limited dependent variable. This method not only uses the 2SLS procedure of purging the stochastic element from the endogenous variable, but it also tests the null hypothesis that the variable is weakly exogenous. The test is based on the exclusion of the stochastic element of the hypothesised endogenous variable and tests the significance of this stochastic element.

85. In practice, this amounts to regressing the discrete insulation ownership variables on actual consumption, other household characteristics, and the fitted residuals from the consumption reduced form. If the coefficient on the fitted residuals is insignificant, we can accept that the stochastic element of C is not correlated with I, and thus that C is exogenous in the insulation ownership equation. We can then estimate the equation without worrying about simultaneity bias. If the coefficient is significant, we cannot conclude that the variable is endogenous, but can reject that it is exogenous, and we must estimate to take into account endogeneity.

86. This process is identical to the 2SLS procedure of including the fitted values of the endogenous variable in the regression. This is apparent upon examination of the relationship between the actual and the fitted values of the reduced form:

$$\hat{C}_i = C_i - \hat{u}_{2i}.$$

87. Therefore, including the actual value of the endogenous variable and the stochastic element in the regression is exactly equivalent to including the fitted value. The estimates of the endogenous variable in this test will be consistent. We describe the results of these tests and procedures in Chapter 10.

8. Estimation

88. The econometric model developed above consists of the estimation of two separate equations, one for fuel consumption and one for ownership of insulation. In the former case, the dependent variable is continuous: fuel consumption takes on a large number of values. In the latter, the dependent variable is discrete: ownership takes the value 1 if the household possesses insulation and 0 if it does not.

89. Whilst the least squares regression model will consistently estimate the coefficients of a large number of regressors based on certain assumptions, it cannot efficiently estimate a model in which the dependent variable can only take on a limited number of values. The disturbances of the regression model are assumed to be identically distributed with a mean of zero. In a discrete choice model such as this, the disturbances are only allowed to take on two values. If the model is defined by the regression equation

$$y_i = \beta' x_i + u_i \tag{8.1}$$

then the only two possible values that u_i can take are

$$u_i = 1 - \beta' x_i \qquad \text{if } y_i = 1$$

and

$$u_i = -\beta' x_i \qquad \text{if } y_i = 0,$$

and this violates the assumption on the distribution of the errors. The least squares (LS) estimates from the linear regression model are inefficient. Non-linear estimation models such as maximum likelihood (ML) techniques are the alternative to LS estimation, and several models incorporating the discrete dependent variable have been developed.

90. The procedure used in this report to estimate the ownership of insulation in both the reduced form and the structural analysis is a probability model based on the assumption of a logistic distribution of the true disturbances, referred to as the Logit model. We define an unobserved response variable, y_i^*, which follows the relationship

$$y_i^* = \beta' x_i + u_i. \tag{8.2}$$

91. This y_i^* is a threshold value for each household. If, for example, $y_i^* > 0$, then the household will make the decision to invest and $y_i = 1$. If $y_i^* \leq 0$, $y_i = 0$ and the investment is not realised. We are modelling the probability that the investment is realised, hence

$$prob(y_i = 1) = prob(y_i^* > 0) = prob(u_i > -\beta' x_i) \tag{8.3}$$

and

$$prob(y_i = 0) = prob(y_i^* \leq 0) = prob(u_i \leq -\beta' x_i). \tag{8.4}$$

92. Assuming the cumulative distribution for the u_i is logistic,[9] we can rewrite the above probabilities as

$$prob(y_i = 1) = 1 - \frac{\exp(-\beta' x_i)}{1 + \exp(-\beta' x_i)} = \frac{\exp(\beta' x_i)}{1 + \exp(\beta' x_i)} \tag{8.5}$$

and

$$prob(y_i = 0) = \frac{1}{1 + \exp(\beta' x_i)}. \tag{8.6}$$

93. This is then plugged into the likelihood function,

$$L = \prod_{y_i = 0} \frac{1}{1 + \exp(\beta' x_i)} \prod_{y_i = 1} \frac{\exp(\beta' x_i)}{1 + \exp(\beta' x_i)} \tag{8.7}$$

and the log of this function is maximised subject to the parameter vector, β. The estimates of β are solved as those values that maximise the likelihood that they are the true parameters of the model.

94. The parameter estimates are not explicitly in terms of probabilities. The signs of the coefficients and the relative magnitudes are comparable, but in order to interpret fully the estimators in terms of probabilities, we must transform the results through the distribution formula, as described in equation (8.5):

$$prob(y_i = 1) = \frac{\exp(\beta' x_i)}{1 + \exp(\beta' x_i)}.$$

95. The form of the logistic distribution ensures that the predicted probabilities will lie between 0 and 1, i.e.

$$0 < prob(y_i = 1) < 1.$$

[9] The cumulative logistic distribution is defined as

$$F(Z) = \exp(Z)/(1 + \exp(Z))$$

and is almost identical to the cumulative normal distribution with slight divergences at the tails. The logistic distribution has been chosen for its computational simplicity.

9. Results: The Reduced Form Model

96. Logit estimates of the reduced form model described in Section 7b are reported for the full data sample in the final columns of Tables A1-A3. A description of the variables included in the estimates is given in Table A9.

97. As well as the estimated coefficients, the standard errors of the estimates are shown, allowing the significance of the estimates to be assessed and allowing the degree of precision achieved by different models to be compared. Asterisks denote variables that are significant at the 10 per cent level on a t test, and double asterisks variables which are significant at the 5 per cent level.

98. In contrast to the ordinary least squares model, comparatively few test statistics are available for evaluating the overall specification and significance of binary response models such as the Logit model used here. Some indication of the overall goodness-of-fit can be derived from the 'pseudo' R^2 reported at the end of the tables.[10] As with the R^2 in OLS models, this is an indicator of the explanatory power of the model. In interpreting the values obtained, it should be borne in mind that the R^2 of cross-sectional models is rarely above 0.3, as the variation of the data in these models is typically much higher than in time-series data.

99. The sample size used for each individual model varies, so as to exclude households which do not face a choice regarding the installation of a certain measure. Thus, in modelling loft insulation, households without lofts have been excluded from the analysis. Any 'Don't know' replies have also been deleted.

100. Interpreting the size of the estimated coefficients in a Logit model is somewhat more difficult than in an ordinary least squares regression equation, since the relationship between the coefficients and the probability of ownership is not linear. The impact of any of the variables on the probability that a household will possess the measure concerned depends on the value taken by each of the other variables. Thus, whilst the sign on the variable representing private tenants, for example, may illustrate that private tenants are (other things being equal) less likely to have loft insulation than owner-occupiers, the size of the impact of 'being a private tenant' on the probability of having loft insulation will vary between households, depending on the values taken by all the other variables. Thus although the model separates out the impact of tenure from the impact of other variables that may be correlated with tenure, the separate contribution of tenure to the probability of having loft insulation depends on the values taken by the other variables.[11]

101. To give an indication of the strength of the effects of the various variables in the estimated models, we present a table of predicted probabilities. This shows the predicted probability of possessing each measure for an individual household, and shows how the probability varies as each of the various factors (income, tenure, etc.) changes. The individual reference household on which the tables of predicted probabilities are based has the characteristics shown in Table 9.1.[12]

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[10] The pseudo R^2 used here is that developed by McFadden (1974).

[11] This is a consequence of the non-linearity of the Logit model, which is required to ensure that predicted probabilities lie between zero and one.

[12] Unlike the choice of a base household in estimation, which is essentially arbitrary and has no impact on the results obtained, the choice of the reference household in these tables influences the size of the calculated probability changes from subsequently varying each factor. In principle, a series of probability tables could be presented, each for a different reference household, and the quantitative impact of the various factors on predicted probabilities would differ, although it would always be in the same direction. The probability tables, based on a single reference household, are thus illustrative, but are not comprehensive.

Table 9.1
Characteristics of the Reference Household
Used in the Tables of Predicted Probabilities

Owner-occupier
Head of household aged between 40 and 59
Average household income
Northern region
Has lived in dwelling for between 10 and 20 years
Terraced house, built before 1900
Average floorspace
Has gas central heating

(a) Loft Insulation

102. The final columns of Table A1 report the full results of estimating the reduced form for loft insulation. The quantitative contributions of each of the significant variables to the overall probability are illustrated in Table 9.2.

Table 9.2
Predicted Probabilities of having Loft Insulation,
for Households with Various Characteristics

Reference household (characteristics as in Table 9.1)	.90
As reference household, but: half average income	.88
As reference household, but: double dwelling area	.86
As reference household, but: tenants in private rented sector	.75
As reference household, but: detached house	.92
As reference household, but: flat	.82
As reference household, but: electricity used for heating	.86
As reference household, but: no central heating	.75
As reference household, but: house built between 1945 and 1964	.96
As reference household, but: residence length less than 2 years	.86
As reference household, but: detached house, built between 1945 and 1964, in South-East region; household income 50% above average	.97
As reference household, but: private rented flat, no central heating, using electricity for heating; residence length under 2 years; household income 80% of average	.17

103. Fourteen of the explanatory variables are found to be significant at the 5 per cent level, including variables representing the type and size of the dwelling, its year of construction, the type of heating, tenure, and the income of the occupants. A further two variables are significant at the less stringent 10 per cent level.

104. Large effects (indicated, in the case of the dummy variables, by the size of the estimated coefficients) are found from:

* tenure: private tenants are found to have a much lower probability than owner-occupiers of possessing loft insulation;
* the date of construction: generally, loft insulation is found to be less likely, the older the property;
* the type of heating: loft insulation is more likely amongst households with central heating, and is less likely where households use electricity for heating than where they use gas.

105. Apart from the effect of income (which has, in any case, only a small quantitative impact on the probability that a household has loft insulation), none of the socio-economic and demographic variables relating to the characteristics of the *occupants* of the property makes a significant contribution to explaining the pattern of possession of loft insulation. Also, the length that a household has been resident in the property, and the likelihood of a future move, appear to have little impact on the pattern of loft insulation. With the exception of a lower probability in London, there are no significant regional differences. House size has a small, generally negative, effect.

106. Amongst the examples shown in Table 9.2, that with the lowest probability of having loft insulation is a private rented flat, without central heating, and using electricity for heating, where the occupant has below-average income, and has been resident for less than two years. For a household with these characteristics, the probability of having loft insulation is only 0.17. This compares with a probability of 0.90 for the reference household, in an owner-occupied terraced house with gas central heating, and an overall actual proportion of ownership across the sample as a whole of about 0.82.

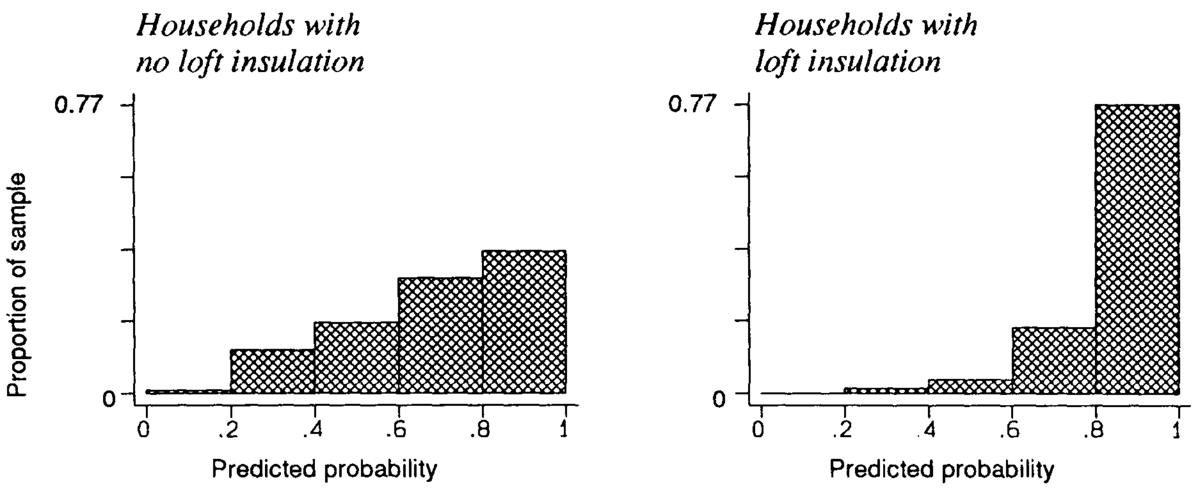
107. The low predicted probability for the private rented flat without central heating is perhaps not particularly surprising, as the occupants of such properties may often be unlikely to remain in the dwelling for a long period of time, and may not therefore be able to realise the returns on the investment in loft insulation. The largest effects on this probability, however, come from the private rental and flat dummies, and the probability of future moves is not found to be significant in the estimated equation. This suggests that the problem in these properties may not relate solely to the short-term nature of the tenancy, so much as to tenure *per se*. It is also possible that the individually appropriable energy savings available from insulation in a flat are lower than in houses.[13]

108. The significance of central heating in the loft insulation estimates (and, indeed, in the other results reported later) may not be surprising, yet it is difficult to interpret. Those households with central heating could be households which choose to heat the house to a higher heating standard, because of the ability of central heating to heat the entire house; in this case, the return on the investment would tend to be higher for dwellings with central heating (as reported in Table 3.2). Another possible reason for the significance of the central heating variable is that it proxies some aspects of the information problem. Those households that are well informed regarding central heating may also be better aware than the average household of the high returns to domestic insulation.

[13] The sample excludes flats which do not have lofts in which insulation could be installed.

Figure 9.1

The Distribution of Predicted Probabilities for Household Possession of Loft Insulation from the Reduced Form Model



109. In Figure 9.1 we show evidence about the extent to which the estimated model succeeds in explaining the differences between households which possess loft insulation and those which do not. This figure shows a histogram of the predicted probabilities obtained using the estimated reduced form model for each individual household in the data sample. These predicted probabilities lie between zero (the model predicts with certainty that the household will not have loft insulation) and one (the model predicts with certainty that the household will have loft insulation). If the model contained *all* of the factors affecting individual differences, the left-hand histogram would be concentrated at zero and the right-hand histogram would be concentrated at the value one. Comparison of the pattern of predicted probabilities for those households actually recorded as possessing loft insulation with the pattern of predicted probabilities for those households which do not possess loft insulation provides an indication of the extent to which variables included in the reduced form model succeed in discriminating between those with and without the measure.

110. Although there are marked differences in the distribution of predicted probabilities between the two groups, it is clear that the variables in the model only explain part of the actual differences between households; and, in particular, the model contains few variables that enable us to identify with any great certainty those households without loft insulation. Variables omitted from the model (such as perhaps informational factors and individual attitudes) thus clearly have an important role in behaviour.

(b) Wall Insulation

111. Given that the estimated savings from wall insulation are large, the very small percentage of households which actually possess wall insulation (about 11 per cent in our data) is perhaps surprising. It also turns out to be more difficult, using the variables we have available, to explain the pattern of ownership of wall insulation than of the other measures.

112. The results in the final columns of Table A2 show that physical factors play the most important role. There is rather more variation by type of house than in the case of loft insulation, and also more regional variation. The type of heating fuel does not contribute significantly to the explanation of the pattern of wall insulation, although, as in the loft insulation equation, the possession of central heating has a positive and significant impact. The probability of having

Table 9.3
Predicted Probabilities of Having Wall Insulation, for Households with Various Characteristics

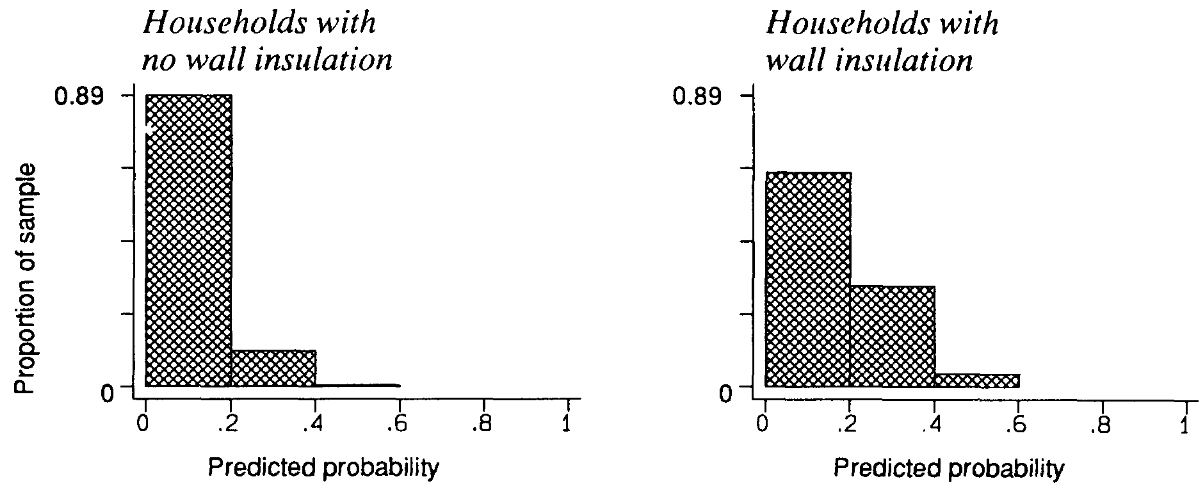
Reference household (characteristics as in Table 9.1)	.11
As reference household, but: half average income	.09
As reference household, but: double dwelling area	.09
As reference household, but: tenants in private rented sector	.08
As reference household, but: detached house	.20
As reference household, but: flat	.07
As reference household, but: electricity used for heating	.10
As reference household, but: no central heating	.07
As reference household, but: house built between 1945 and 1964	.18
As reference household, but: residence length less than 2 years	.09
As reference household, but: detached house, built between 1945 and 1964, in South-East region; household income 50% above average	.40
As reference household, but: private rented flat, no central heating, using electricity for heating; residence length under 2 years; household income 80% of average	.02

wall insulation is higher amongst more recently-built dwellings than amongst older ones; it is also higher amongst households which have been living in the property for a medium period, than for those which have only just moved in. As with loft insulation there are few significant socio-economic effects. Table 9.3 shows some predicted probabilities of having wall insulation, based on the estimated equation, for the same example households as in Table 9.2.

113. The predominance of physical factors could lead to the conclusion that the pattern of take-up of wall insulation is, for the most part, a characteristic of the building, rather than its inhabitants, and it is the building industry that is responsible for most of the wall insulation in dwellings in the UK. Many respondents did not know whether they had wall insulation (more than for any of the other insulation measures). The EHCS has no information on the origination of wall insulation (i.e. whether it was installed during building or whether it was installed by the household), so there is no way of checking this.

114. The strongly significant negative effect of flats and semi-detached and terraced houses over the base detached house could reflect one of two influences. The 'need' for insulation and the individual energy saving for each household may be lower in a semi-detached or terraced house or a flat because they have fewer exposed walls. Alternatively, the lower probability of wall insulation could arise from decision-making problems associated with the shared ownership of walls: organisation and information problems would tend to increase with the number of households participating in the decision.

Figure 9.2
The Distribution of Predicted Probabilities for Household Possession of Wall Insulation from the Reduced Form Model



115. Figure 9.2 suggests that the predictive power of the estimated model is weak; few of the households recorded as having wall insulation are predicted to have a probability of possessing wall insulation of greater than 0.5. On the basis of the 'score tests' sometimes used to evaluate binary response models, the model for wall insulation would thus predict poorly, failing to identify all but a handful of those households with wall insulation. However, closer examination of the distribution of predicted probabilities indicates a degree of explanation, in that the households with wall insulation are much less likely to be given a very low probability than those without. The model thus identifies *some* of the factors giving rise to differences between households, although clearly there are important omitted influences.

116. A further consideration with regard to wall insulation is the type of wall insulation that is installed and the amenability of the dwellings to install specific types of wall insulation. There are three ways in which walls may be insulated: internal solid wall insulation, external solid wall insulation, and cavity fill insulation. Of the three, cavity fill is the only type of wall insulation that can be installed without requiring major reconstruction or redecoration of the inner or outer walls, and it therefore tends to be the only cost-efficient method of insulating walls except when other work is needed on the dwelling (see Pezzey (1984)). The results in the final columns of Table A2 report the probabilities of possessing *any* type of wall insulation, and the sample of households on which estimation is based includes all households and not just those with cavity walls.

117. In practice, there might be two reasons why we would wish to narrow the focus to cavity walls alone. Firstly, cavity wall insulation is the only type of wall insulation where the decision to install it can be taken purely on the basis of the energy savings; other types of wall insulation can only be done on a cost-effective basis when other building works are undertaken. Including these other types of insulation will include some for which the factors affecting individual decisions are much wider than simply the energy-saving characteristics. Secondly, if we include in the estimation the households without cavity walls, we base the estimates on a sample which includes households which are *unable* to install the main type of wall insulation, and the estimated coefficients are therefore likely to be biased and imprecise.

118. To take account of this statistical point, we have estimated a second model, by choosing a sub-sample of dwellings that we can be reasonably sure will have cavity walls. Whilst many older houses do not have cavity walls, cavity walls have been required by legislation throughout the post-war period; selecting a sample of dwellings built since 1945 will thus select a sample that could install cavity wall insulation. Moreover, given that they can install cavity insulation, it is likely that if they install any insulation it will tend to be of this type.

119. The results reported in Table A7 compare the estimates over the entire sample with those obtained from estimating over the sample of post-1945 dwellings (those with cavity walls). In the results reported in the second column of Table A7, the dependent variable is still whether the dwelling has any type of wall insulation, but the sample has now isolated only those dwellings with cavity walls. Comparing column 1 with column 2 in Table A7, there are slightly fewer significant explanatory variables in the model estimated on the post-1945 sample (partly because of the reduced sample size), but the overall level of explanation of the variation in the data, as measured by the 'pseudo-R^2', is slightly higher. A number of the significant coefficients, including the income coefficient, are somewhat larger in the post-1945 model; otherwise the main difference is that the central heating dummy has a smaller and less significant coefficient in this model.

(c) Double Glazing

120. The double glazing estimation (Table A3) has the highest explanatory power of all of the equations estimated, with many significant variables. Size, house type, house age, the heating fuel, the presence of central heating, tenure, and the length of residence all contribute to the probability of double glazing being present. In most cases, the direction of these effects matches that in the models for the other insulation measures, but there is a clear difference in the impact of electric heating. In the models for loft insulation and wall insulation, electric heating tended to reduce the probability of having the measure; in this model, households are *more* likely to have double glazing if they use electricity for heating.

121. Although the pattern of insulation measures across income groups shown in Figure 6.2 suggests that the take-up of double glazing is more related to income than the take-up of other insulation measures, this effect does not appear to be borne out by the estimates here, in which the effect of income can be separated from the effects of other influences correlated with income. The income coefficient reported in Table A3, while significant, is no greater than the income coefficient in the estimates for either loft insulation or wall insulation.

122. Double glazing has significant regional variation. London and the South-East have the highest probability of households possessing double glazing, perhaps reflecting the investment into increasing house values during the 1980s housing boom. Double glazing is also highly responsive to house age, reflecting the amenability of more recently-built houses to the installation of double-glazed windows.

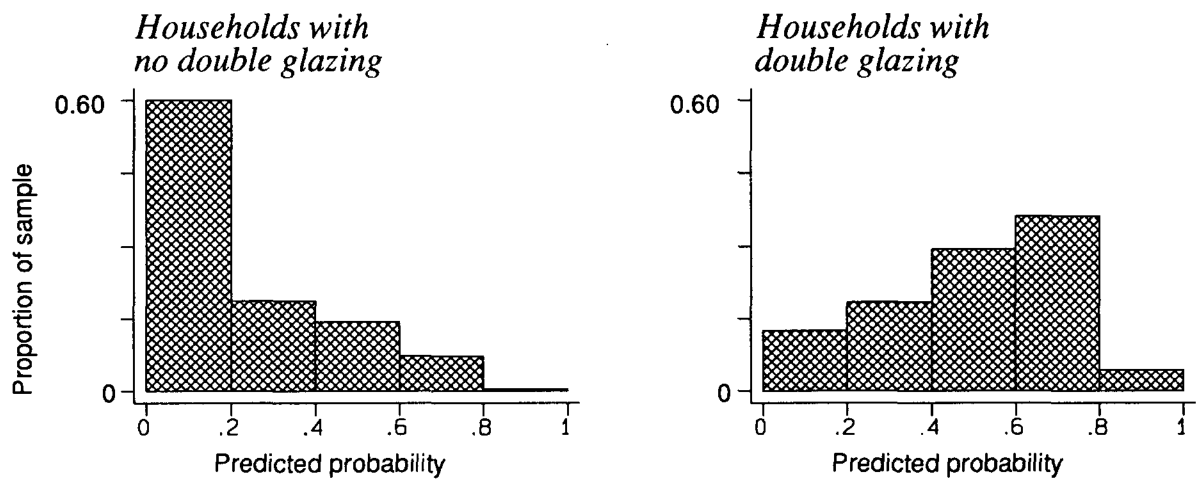
123. The model shown in Table A3 estimates the probability of having at least one window in the dwelling double glazed. Table A8 shows a second estimated model, where the dependent variable only takes the value one if the entire house is double glazed. The reason for being interested in this is that full double glazing is more visible and its benefits may be more likely to be taken into account by potential house purchasers. Also, the notion of partial double glazing is less precise, and can range from one room to almost the whole house being double glazed. The effects of the various explanatory variables are broadly similar between 'full' and 'any' double glazing, although the results for full double glazing show a different regional pattern. Full double glazing was also found to be more likely in more recently-built properties. The probability of full double glazing seems to be less sensitive to residence length than the probability

Table 9.4
Predicted Probabilities of Having (Any) Double Glazing, for Households with Various Characteristics

Reference household (characteristics as in Table 9.1)	.36
As reference household, but: half average income	.32
As reference household, but: double dwelling area	.38
As reference household, but: tenants in private rented sector	.12
As reference household, but: detached house	.49
As reference household, but: flat	.34
As reference household, but: electricity used for heating	.43
As reference household, but: no central heating	.21
As reference household, but: house built between 1945 and 1964	.61
As reference household, but: residence length less than 2 years	.26
As reference household, but: detached house, built between 1945 and 1964, in South-East region; household income 50% above average	.84
As reference household, but: private rented flat, no central heating, using electricity for heating; residence length under 2 years; household income 80% of average	.05

of any double glazing. Income is no longer a significant variable in the model for full glazing, which would be consistent with the view that full glazing was undertaken as an investment to obtain benefits from reduced future energy costs.

Figure 9.3
The Distribution of Predicted Probabilities for Household Possession of Double Glazing from the Reduced Form Model



124. Figure 9.3 shows that the estimated reduced form model results in a considerably different pattern of predicted probabilities of possessing double glazing amongst those who actually have double glazing, compared with those who actually do not.

(d) Other Insulation Measures

125. A reduced form model for draught proofing along the lines of those for double glazing, loft insulation, and wall insulation was found to have very little explanatory power and few effects which were significantly different from zero. One reason why the estimation of a model for draught proofing may be less satisfactory than the other models is that the definition of draught proofing may be rather wide and may encompass a very diverse set of measures taken by households.

126. Water tank insulation has the most complete level of take-up of all insulation measures covered by the data, as well as having the greatest returns (as calculated in Pezzey (1984)). Results for reduced form models of water tank insulation face the problem that there is little variation left to explain, and the reasons why the few households in the sample which do not have the measure are in this position may reflect largely specific characteristics of the household which are not captured by the broad social and economic variables available to us. For this reason, results for water tank insulation have proved to be considerably less interesting than for the three principal measures discussed above.

10. Results: The Structural Model

127. As we have noted, it is difficult to interpret the coefficients in the reduced form models of energy efficiency investment described in the previous chapter; the various social and economic variables which are found to be related to the probability of possession of a particular energy efficiency measure may reflect the impact of market failures in energy efficiency investment, but could equally well be due to the influence of social and economic factors on the demand for warmth. The structural model aims to disentangle these two channels of influence.

128. The structural model consists of two equations, one a reduced form model for domestic fuel consumption, and the second equation representing the insulation decision. For the reasons set out in Chapter 6, the fuel consumption model has to be estimated on a smaller sample than the reduced form models of Chapter 9. The structural model is thus estimated using data for those households for which fuel consumption data are available and, of these, only those households which use gas as the main fuel for heating. We describe the two equations of the structural model in turn.

(a) Fuel Consumption

129. The fuel consumption equation in this report is intended simply as an input to the estimation of the energy efficiency investment models, and thus appears as a reduced form, in which each household's fuel consumption is related to a set of exogenous variables. The fuel consumption equation thus excludes the energy efficiency measures, even though these would be expected to influence fuel consumption, since these are endogenous variables in the system being estimated. Interpretation of the results of the fuel consumption equation is thus somewhat problematic, and the equation does not allow us to draw clear conclusions about the influences on households' fuel consumption behaviour. Indeed, if our focus of interest had been on fuel consumption, it would have been appropriate to reverse the structure of the models, using reduced form models for the various energy efficiency investments as inputs to the estimation of a structural equation for energy consumption, including the effects of energy efficiency investments on consumption. Nevertheless, although these caveats are important, it is interesting to examine the results of estimating the reduced form fuel consumption model, before proceeding to the structural equation for each of the investments.

130. The results for the fuel consumption equation are reported in Table A4 (and reproduced in Tables A5 and A6). The dependent variable is the log of gas consumption. The independent variables include a wide range of socio-economic variables and variables describing the features of the property, including a number of interactive terms. In addition, the independent variables include the numbers of children of different ages in the household; these variables are not included in the models for energy efficiency investment, a restriction which permits statistical identification of the investment equations.

131. The estimated income elasticities from the fuel consumption equation may be of some interest in their own right. Because of the inclusion of interactive income effects, the tenure, pensioner, and central heating dummies in the consumption equation include the intercept term of the income relationship, and this needs to be taken into account in interpreting the estimated coefficients on these variables. These interactive terms and the inclusion of a squared term in income allow each individual household to have a unique income elasticity. The average calculated income elasticities for each of a number of household types are set out in Table 10.1.

Table 10.1
Estimated Average Income Elasticities for Fuel Consumption

Owner-occupier	0.128
Local authority tenant	0.109
Private renter	0.033
Household with central heating	0.135
Pensioner household	0.069

132. The elasticities confirm the results of other studies of household energy demand that domestic fuel has the demand characteristics of a 'necessity' - in other words, a 1 per cent change in income will result in less than a 1 per cent change in domestic fuel use. The income elasticity is especially low for private renters and pensioner households.

(b) Energy Conservation Measures

133. The second equation shown in Tables A4-A6 shows the structural model estimated for the three energy efficiency measures - loft insulation, wall insulation, and double glazing - using as inputs the results of the reduced form for gas consumption. As described in Section 7b, the reduced form is used to generate predicted levels of fuel consumption, which are then used in place of actual fuel consumption in the insulation equations. There are two equivalent ways in which this can be done.

134. Frequently the endogeneity of the consumption equation is assumed, and the fitted values from the reduced form are included in the second equation. In this case we have taken the alternative approach of including the actual values for fuel consumption and the residuals from the fuel equation (i.e. the difference between the actual level of fuel consumption and that predicted by the fuel consumption reduced form), allowing the Smith-Blundell exogeneity test to be conducted. This test takes the form of a t test on the residuals from the consumption reduced form in the investment equation. In all three models the t statistic is not significant at the 5 per cent level. This implies, perhaps surprisingly, that current levels of consumption do not appear to be generated endogenously by the system of two equations that we set out in the theoretical model; instead, from the point of view of statistical estimation, we can treat consumption as an *exogenous* variable in the estimation of the insulation models.

135. Results of the three insulation models estimated on this basis are reported as the first columns in Tables A1-A3. Actual fuel consumption levels are included as explanatory variables, without any correction for simultaneity being needed. In the equations for loft insulation and double glazing, fuel consumption levels are not statistically significant on the basis of a t test at the 10 per cent level; in the equation for wall insulation, consumption is significant at the 10 per cent level, but has an unexpected negative sign.

136. In practice, the importance of including the data on fuel consumption in the insulation equations appears to be very limited. The first and second equations in Tables A1-A3 show, respectively, the structural model and a reduced form which is identical to the structural model except that the consumption variable has been excluded. In the case of none of the three insulation measures does the exclusion of fuel consumption from the estimated model appear to make any major change to the coefficients on the other variables. The reduced form estimated on the sub-sample, shown as the second equation in Tables A1-A3, would thus appear to be as informative as the structural model including consumption. This suggests, moreover, that the

results of the reduced form models described in Chapter 9 (and which appear as the third column of results in each of Tables A1-A3) may in fact be rather informative about the nature of the various influences on insulation decisions. In general, if the comparison of the structural and reduced form models on the sub-sample of gas users can be extrapolated to the whole sample, the estimated coefficients on the variables in the reduced form relate to direct influences on investment in energy efficiency, rather than indirect influences operating through the level of household fuel consumption. We would thus appear to be able to draw inferences from the reduced form model about the influence of the various social and economic variables that may indicate market failures in the market for energy efficiency.

11. Implications of the Results

137. What conclusions can be drawn from the empirical results presented in this report about the factors influencing households' decisions to invest in energy efficiency measures? Broadly speaking, the results provide evidence of two sorts. Firstly, they provide some indications about the conformity or otherwise of actual household decision-making to the optimising model of household decisions set out in Chapters 2, 3, and 7. Secondly, the results provide evidence about the practical significance of some of the possible sources of market failure set out in Chapter 4.

138. The optimising model of household energy efficiency decisions described in this report is one in which such decisions are investment decisions, to be taken on the basis of an assessment of the net present value of the anticipated future savings from the investment, minus the initial costs. Generally, the likelihood that a particular investment would be undertaken would be positively related to expected future energy prices and the quantitative reduction in household energy use for a given standard of heating, and negatively related to the cost of undertaking the measure and the discount rate. Some of these factors are unobservable (for example, expectations about future energy prices), whilst some aspects of others (for example, the contribution of the price of materials to installation costs) cannot be studied with the single year of cross-section data which we have available.

139. Nevertheless, the importance of the physical characteristics of the dwelling in explaining the pattern of possession of energy efficiency measures does appear to be an indication that individual household decisions conform, to some extent at least, with the optimising model. The most obvious interpretation of these variables is that they reflect differences in the cost of undertaking a particular measure. In general, too, the signs of the physical variables are consistent with this interpretation. Dwelling size, for example, tends to be negatively related to the probability of ownership of both loft insulation and wall insulation. The type of house, too, may act as a proxy for the cost of insulation.

140. The household's possession of central heating plays an important role in the models; other things being equal, households with central heating are more likely to have each of the measures studied. There are a number of possible interpretations of this result. One, which reflects the higher rates of return to energy efficiency investments in well-heated houses, is that the central heating variable proxies the standard of heating of different houses, and the positive sign on the central heating variable thus reflects a tendency for households to be more likely to undertake energy efficiency measures where the gains are greater. On the other hand, finding a relationship between energy efficiency investment and the possession of central heating could also reflect differences in awareness and attitudes to investments in that those households which have invested in central heating are better informed than the average, or are the type of households that invest in home improvements more generally.

141. On the other hand, the results find no relationship between household energy use and the probability that the household will possess loft insulation, wall insulation, or double glazing. On the face of it, this would appear to count against the optimising model, since households with higher energy use will, *ceteris paribus*, be households which stand to make greater monetary savings from energy efficiency. However, there are reasons which could account for the absence of the expected relationship. In particular, current household energy consumption may be a poor guide to the expected future level of energy consumption of the household when it made its decision. Household energy consumptions may change over the life cycle, reflecting different patterns of work, family composition, and other factors affecting the need for domestic heating. Also, given the nature of the data we have used, the household installing a measure may not be

the same as the household occupying the property at the time of the survey - and for households which intend to move in the future, their own particular consumption patterns may be less relevant to the decision than the average consumption of future occupiers.

142. Finally, some support for the notion that energy efficiency decisions are primarily *investment* decisions is provided by the rather small role found for household income in the results. Viewed purely as an investment decision, undertaken purely to benefit from the future reduction in energy costs, households' decisions about energy efficiency would only be expected to be influenced by income indirectly, through the effect of income on energy consumption. The tables of predicted probabilities (Tables 9.2, 9.3, and 9.4 for loft insulation, wall insulation, and double glazing respectively) show that differences in household income *on their own* have very little impact on the predicted probability that a household will have each measure; other variables have a much greater impact on the predicted probability. Thus, even though the effect of income is found to be statistically significant in the estimated equations, its quantitative impact is small. Of course, some of the problems noted above with respect to household energy consumption also apply to household income, and could thus explain the small effects found. On the other hand, there may well be greater variation in household energy consumption patterns amongst the different occupants of a particular house than in household incomes, and current income may therefore be a reasonable indicator of the income relevant at the time the installation decision was made.

143. As far as the significance of market failures is concerned, there are three main observations to be made.

144. Firstly, socio-economic variables prove to be rather unimportant in the results. No effect is found of employment status (short-term or long-term unemployment) and comparatively small effects are found of the age of the head of household and the variable identifying households where the head of household is a pensioner. In addition, although a small income effect is found, this does not appear to be greater for those households in income groups where credit constraints would be most likely than it is across the population as a whole; squared terms in income were rejected by the data, and so the income effect appears to be broadly linear in the log of income. Thus, although it is not possible to say from this analysis whether all households make decisions using discount rates which are inappropriately high or based on unduly short time horizons, the evidence does not indicate that there are large and *systematic* differences in discount rates between households that might be attributed to binding credit constraints affecting certain groups of households.

145. This observation is subject to a number of important qualifications. Firstly, as observed above, the income relevant at the time of the insulation decision may differ from the income of the household observed at the time of the survey. Secondly, the observed pattern of possession of energy efficiency measures will reflect the influence of past policies and incentives in various ways. To the extent that these policies have been targeted on low-income households, either by grants and financial incentives or through direct provision and intervention in certain parts of the housing stock predominantly occupied by lower-income households, they may have succeeded in eliminating income-related differences in the pattern of possession of energy efficiency measures that would otherwise have existed. The observation that there were only small income-related differences in the pattern of possession of energy efficiency measures does not, therefore, demonstrate that credit constraints have no influence on take-up. Rather it indicates that, *given* the pattern of income-related assistance that was available at the time of the 1986 survey, credit constraints do not appear to have had a serious influence then on the pattern of energy efficiency investments.

146. Secondly, there are major and significant differences in energy efficiency investments related to tenure. The probability of a household possessing any of the three measures studied is higher, other things being equal, amongst owner-occupiers than amongst private tenants, and the probability that a household has double glazing is higher amongst owner-occupiers than council tenants (see Tables 9.2-9.4). Of course, higher levels of energy efficiency investment amongst owner-occupiers have been observed in tabulations of the pattern of such measures (see for example Table 3.1). However, unlike the regression models studied here, these tabulations do not hold other factors constant. The results of this report provide the first evidence that this difference between tenure groups is genuinely related to tenure, and not to income or some other factors correlated with tenure and take-up, and thus provide empirical support for the presence and the importance of tenure-related market failures.

147. Thirdly, the overall explanatory power of the models provides an indication of the importance of factors not included in the EHCS data and the estimated models. If we take the 'pseudo R^2' of each model as a measure of the proportion of the overall variation between households which is explained by the variables included in the model, we find that this does not rise above 25 per cent for any of the models. This is by no means unusual for cross-section models of household behaviour. However, it does indicate the considerable scope for other influences, not included in the models, to have significant effects on household energy efficiency investments. Amongst these effects, informational market failures may well be important, and there is considerable room for attitudinal factors (see, for example, Hedges (1991)) and other influences omitted in the present analysis to contribute to differences in individual behaviour.

148. In addition to the above principal conclusions regarding market failure, some of the results of the analysis are suggestive of other market failure problems. We have observed the low overall level of significance in the equations for wall insulation. Apart from some physical factors and tenure, the variables included in the analysis contribute little to an explanation of the pattern of take-up of wall insulation. The lack of investment in this area may partly be attributable to poorer information than in other areas. Lower levels of investment in semi-detached and terraced houses and flats than in the baseline detached house may partly reflect the lower need for wall insulation in such properties (since adjoining houses act as an alternative form of insulation). However, it may also reflect the decision-making problems that could arise where some walls are shared and decisions therefore have to be made jointly by more than one household.

149. Finally, the relationship between residence length and the probability that a household will be observed with energy efficiency measures seems to suggest that levels of investment may be lower where households move frequently - possibly because owner-occupiers do not expect the benefits of energy efficiency measures to be adequately capitalised into house prices. There are, however, two reasons to be cautious about this interpretation. Firstly, the variable identifying households which expect to move in the next two years does not show the same effect. Secondly, the effect of residence length is in fact strongest on double glazing, which is the most easily observed of the three measures, and therefore, perhaps, the most likely to be capitalised into house prices.

12. Conclusions

150. This report has sought to assess the influence of social and economic variables on households' investments in domestic energy efficiency, using the tools of microeconomic analysis. It complements existing studies on energy efficiency investment, including studies based on technical data and surveys of householders' perceptions and attitudes.

151. Part 1 of the report (Chapters 2-5) has considered the economic basis for household decisions about a range of energy efficiency investments, such as the installation of loft insulation, wall insulation, double glazing, draught proofing, and hot water tank insulation.

152. Each of these insulation measures has the character of an investment decision: an initial outlay of the cost of the insulation is made in the first year, and benefits are gained in the form of decreased energy costs over a number of subsequent years. Investment calculations of the *net present value* of each of the insulation measures suggest that all (with the possible exception of double glazing) have a positive net present value and, hence, are cost-effective investments. This appears to be somewhat at odds with the current low level of possession of some of the insulation measures.

153. There are two broad reasons which might explain the apparent discrepancy. Firstly, as Chapter 3 has described, a number of the assumptions made in the calculation of the net present value may not fully reflect all the relevant costs and benefits that a householder might wish to take into account in making a decision to invest in energy saving. There may be important hidden costs in the form of 'hassle' and DIY labour time which are not included in the calculations, and the results may also be very sensitive to the assumptions that are made about future energy prices and the appropriate rate of discount. A second explanation, and the one that this report has attempted to examine empirically, is that there may be some important market failures affecting energy efficiency investments.

154. The possible sources of market failure were analysed in Chapter 4 under four headings: informational problems, non-optimisation, the difficulty of appropriating all the benefits from the investment, and credit market failures.

(i) Lack of information held by consumers can either be a simple problem of inadequate dissemination of existing information about the general properties of the various possible measures and their applicability to individual dwellings, or it can consist of a more intractable problem of the natural asymmetry of information between the buyers and sellers of insulation materials.

(ii) 'Non-optimisation' may arise where households make decisions about energy efficiency on the basis of inappropriate criteria. Even where households have ample information about the potential benefits of energy saving, the appropriate decision rule is complex and may be beyond the capacity of some householders.

(iii) Difficulty in appropriating the benefits of energy efficiency investments is in practice likely to be a problem closely related to the pattern of housing tenure. Cost-effective investments may not be undertaken if the person who benefits from energy efficiency improvements is not the person who pays for them. This may be a problem in owner-occupied houses where the current occupant expects to move before recouping the costs of the energy-saving measures, and there may also be problems in tenanted housing where the tenant bears the responsibility for paying energy bills but the landlord has responsibility for making any capital investments in the property.

(iv) Credit market failures may restrict certain sections of the population from investing in insulation measures because of their inability to borrow.

155. Part 2 of the report (Chapters 6-11) has used cross-sectional micro-data from the 1986 English House Condition Survey to estimate an economic model of the pattern of possession of energy efficiency measures across individual households. The results of this estimated model have then been used to assess the practical importance of the various potential sources of market failure set out in the first part.

156. The EHCS data are particularly well suited to model household energy-saving decisions, since they include information both on the physical characteristics of the dwelling and on the incomes, energy spending, and other socio-economic characteristics of the current occupants.

157. Models of two sorts have been estimated. The first is a simple 'reduced form' model, in which each household's possession of loft insulation, wall insulation, or double glazing is related to a wide range of physical characteristics of the property and socio-economic characteristics of the occupants. In comparison with simple cross-tabulations of the data, this approach has the advantage that it allows the individual contribution of each of the factors to be assessed, independently of the effect of other, related, factors.

158. Given that the data relate to only a single year, we have been restricted to a relatively simple 'one-period' model, which includes no dynamics and in which it is implicitly assumed that the socio-economic characteristics of the current occupiers are similar to those of the occupiers when the energy-saving measures were installed.

159. A second 'structural' model has also been estimated. This is based on a simple system of two equations; the first equation describes the factors that influence the decision to insulate, one of which is the current consumption of domestic fuel, and the second equation describes those factors that influence the consumption of domestic fuel. The point of doing this is that it allows us to distinguish the *direct* effects of social and economic factors on the insulation investment decision from the possible *indirect* effects of social and economic factors on the insulation decision via their influence on energy consumption. Market failures would only be indicated by the influence of social and economic variables on insulation arising through the first of these channels.

160. Fuel consumption data are only available for a subsection of the entire sample, and the structural estimation of the system of equations is therefore limited to a sample size of about one-fifth of the original full data set. In practice, our results indicate that the more complex structural model is no significant improvement on the reduced form model, and in view of the greater sample size on which we can estimate the reduced form model, we have based our conclusions on the results from the full sample reduced form estimation.

161. Using the estimated model we have calculated the predicted probabilities of possessing loft insulation, wall insulation, and double glazing under different household circumstances. These have shown, firstly, the range of factors affecting energy efficiency investments by households, secondly, how much some of the hypothesised market failures affect the possession of insulation, and, thirdly, how various inferences can be made regarding the influence of the unmeasurable sources of market failure.

162. The importance of many of the physical characteristics of the dwelling in explaining the pattern of possession of energy efficiency measures is consistent with the notion that some form of optimising investment behaviour underlies the pattern of individual household decisions. Variables which indicate such things as the size of the dwelling, the number of exposed walls, and the ownership of central heating are directly related to either the cost or the level of savings available from the installation of insulation.

163. As far as market failures are concerned, there is clear evidence of a strong effect from tenure. The probability of a household possessing any of the three measures studied is higher, other things being equal, amongst owner-occupiers than amongst private tenants, and the probability that a household has double glazing is higher amongst owner-occupiers than it is amongst council tenants. This suggests that the difficulty of appropriating the benefits of investments in energy-saving measures in private tenanted properties has led to under-investment in energy saving in these properties.

164. In comparison, evidence that the energy saving of segments of the population may be inhibited by credit constraints is harder to find. No effect is found on energy efficiency investment of long-term unemployment or the age of the head of the household - both of which may indicate groups particularly prone to credit constraints - and the effect of income is small and proportionally constant over different income groups. It is not possible to say from this analysis whether *all* households make decisions using discount rates which are inappropriately high or based on an unduly short time horizon. But this study finds no systematic differences between households that would suggest that credit constraints affecting certain groups of households more than others were a significant factor in explaining the take-up of measures found in the 1986 EHCS survey, in the economic conditions prevailing, and given the pattern of policy interventions at that time.

165. Finally, the low overall explanatory power of the models provides an indication of the importance of factors not included in the EHCS data and in the estimated models. In each of the models a large part of the differences between individual households is not explained by the various factors included in the analysis. Whilst this is not unusual in cross-sectional estimation, it does indicate the considerable scope for factors not included in the EHCS data and the estimated models, such as attitudes and informational market failures, to have an effect on household energy efficiency investments.

Appendix

Table A1

Logit Estimations of the Ownership of Loft Insulation: A Comparison of Models

	ESTIMATED WITH SUB-SAMPLE					ESTIMATED WITH FULL SAMPLE		
	1		2			3		
	Structural Model		Reduced Form			Reduced Form		
Variable	β	s.e.	β	s.e.	Mean	β	s.e.	Mean
Ln Income	-0.02	0.20	-0.04	0.20	8.72	0.30	0.08 **	8.64
Perimeter	-0.05	0.23	-0.06	0.23	10.34	-0.25	0.07 **	10.48
Area	-0.003	0.010	-0.003	0.009	111.05	0.006	0.002 **	116.17
Head 26-39	0.63	0.44	0.63	0.44	0.31	0.17	0.20	0.29
Head 40-59	1.09	0.47 **	1.08	0.47 **	0.36	0.07	0.20	0.36
Head 60+	1.67	0.65 **	1.67	0.65 **	0.29	0.09	0.25	0.31
Pensioner	-1.03	0.54 *	-1.04	0.54 *	0.23	-0.08	0.19	0.25
Unemployed	-0.49	0.58	-0.53	0.57	0.02	0.03	0.24	0.03
Unoccupied	-0.67	0.44	-0.68	0.44	0.04	0.02	0.19	0.05
LA/HA	0.03	0.28	0.04	0.28	0.20	0.06	0.12	0.24
PRented	-2.04	0.38 **	-2.04	0.38 **	0.03	-1.10	0.12 **	0.08
Semi-det	0.41	0.40	0.43	0.40	0.36	0.03	0.14	0.35
Terraced	-0.57	0.39	-0.55	0.39	0.48	-0.28	0.15 *	0.44
Flat	-1.16	0.54 **	-1.14	0.54 **	0.04	-0.98	0.20 **	0.05
Electric						-0.42	0.13 **	0.08
Other fuel						0.48	0.10 **	0.20
Shared fuel						-1.82	0.72 **	0.002
Midlands	0.07	0.25	0.07	0.25	0.21	-0.14	0.11	0.20
E Anglia	-0.09	0.47	-0.07	0.47	0.05	0.00	0.19	0.05
S East	-0.30	0.30	-0.29	0.30	0.15	-0.01	0.13	0.15
London	0.19	0.29	0.20	0.29	0.17	-0.33	0.13 **	0.12
West	-0.44	0.38	-0.42	0.38	0.06	0.08	0.14	0.11
Res 2<5yrs	0.02	0.35	0.01	0.35	0.20	0.20	0.14	0.18
Res 5<10yrs	-0.31	0.35	-0.32	0.35	0.19	0.10	0.14	0.18
Res 10<20yrs	-0.42	0.36	-0.44	0.36	0.22	0.40	0.15 **	0.21
Res 20+yrs	-0.59	0.38	-0.62	0.38	0.25	0.12	0.15	0.26
Move likely	0.14	0.25	0.14	0.25	0.17	-0.05	0.11	0.16
Built 1900-18	0.12	0.27	0.12	0.27	0.13	0.22	0.13 *	0.11
Built 1919-44	0.08	0.25	0.08	0.25	0.34	0.50	0.12 **	0.31
Built 1945-64	0.63	0.37 *	0.64	0.37 *	0.18	0.97	0.16 **	0.17
Built 1965+	1.39	0.63 **	1.40	0.63 **	0.09	0.48	0.19 **	0.08
CentHeat	1.16	0.23 **	1.09	0.21 **	0.71	1.12	0.09 **	0.65
Fuel consumption	-0.14	0.21						
Constant	2.80	2.49	2.24	2.36	1.00	0.24	0.87	1.00

Number of obs	= 1294	Number of obs	= 1294	Number of obs	= 5271
$Chi^2(30)$	= 188.4	$Chi^2(29)$	= 187.9	$Chi^2(32)$	= 765.0
'Pseudo' R^2	= 0.185	'Pseudo' R^2	= 0.185	'Pseudo' R^2	= 0.156
Mean of dep var	= 0.866	Mean of dep var	= 0.866	Mean of dep var	= 0.825

** Denotes a significance level of 5%.
* Denotes a significance level of 10%.

Table A2
Logit Estimations of the Ownership of Wall Insulation:
A Comparison of Models

	ESTIMATED WITH SUB-SAMPLE					ESTIMATED WITH FULL SAMPLE		
	1		2			3		
	Structural Model		Reduced Form			Reduced Form		
Variable	β	s.e.	β	s.e.	Mean	β	s.e.	Mean
Ln Income	0.06	0.20	0.02	0.20	8.72	0.34	0.09 **	8.56
Perimeter	-0.09	0.26	-0.14	0.27	10.34	-0.10	0.05 *	10.21
Area	0.00	0.01	0.00	0.01	111.05	0.002	0.002	110.70
Head 26-39	0.06	0.58	0.05	0.58	0.31	0.14	0.23	0.28
Head 40-59	0.12	0.60	0.09	0.60	0.36	0.25	0.24	0.33
Head 60+	0.68	0.66	0.67	0.66	0.29	0.48	0.27 *	0.33
Pensioner	-0.78	0.40 *	-0.79	0.40 **	0.23	-0.38	0.19 **	0.27
Unemployed	-1.34	1.05	-1.38	1.05	0.02	0.18	0.26	0.03
Unoccupied	-0.08	0.47	-0.05	0.47	0.04	-0.27	0.24	0.06
LA/HA	-0.27	0.27	-0.26	0.27	0.20	-0.10	0.12	0.31
PRented	0.12	0.65	0.11	0.65	0.03	-0.36	0.20 *	0.10
Semi-det	-0.59	0.28 **	-0.55	0.28 **	0.36	-0.56	0.12 **	0.31
Terraced	-0.53	0.30 *	-0.45	0.30	0.48	-0.71	0.14 **	0.39
Flat	-0.59	0.58	-0.51	0.58	0.04	-1.16	0.21 **	0.16
Electric						-0.08	0.16	0.10
Other fuel						0.05	0.11	0.18
Shared fuel						-0.24	0.49	0.01
Midlands	-0.04	0.24	-0.03	0.24	0.21	0.03	0.12	0.19
E Anglia	-0.32	0.43	-0.22	0.43	0.05	0.16	0.19	0.04
S East	0.02	0.25	0.04	0.25	0.15	0.25	0.12 **	0.14
London	-1.03	0.34 **	-1.03	0.34 **	0.17	-0.82	0.18 **	0.17
West	-0.02	0.36	0.02	0.36	0.06	0.38	0.14 **	0.10
Res 2<5yrs	0.22	0.35	0.19	0.35	0.20	0.13	0.14	0.19
Res 5<10yrs	0.63	0.35 *	0.60	0.35 *	0.19	0.46	0.14 **	0.17
Res 10<20yrs	0.67	0.35 *	0.62	0.35 *	0.22	0.30	0.15 **	0.21
Res 20+yrs	0.26	0.39	0.21	0.39	0.25	0.22	0.16	0.24
Move likely	-0.42	0.27	-0.42	0.27	0.17	-0.14	0.12	0.18
Built 1900-18	0.08	0.35	0.09	0.34	0.13	-0.22	0.18	0.11
Built 1919-44	0.19	0.29	0.20	0.29	0.34	0.02	0.13	0.28
Built 1945-64	0.86	0.31 **	0.88	0.31 **	0.18	0.56	0.14 **	0.19
Built 1965+	0.77	0.33 **	0.81	0.33 **	0.09	0.77	0.15 **	0.11
CentHeat	1.15	0.28 **	0.94	0.26 **	0.71	0.58	0.11 **	0.65
Fuel consumption	-0.42	0.22 *						
Constant	-0.04	2.57	-1.74	2.44	1.00	-4.55	0.94 **	1.00

Number of obs	= 1294	Number of obs	= 1294	Number of obs	= 6374
$Chi^2(30)$	= 93.02	$Chi^2(29)$	= 89.45	$Chi^2(32)$	= 400.8
'Pseudo' R^2	= 0.095	'Pseudo' R^2	= 0.091	'Pseudo' R^2	= 0.090
Mean of dep var	= 0.126	Mean of dep var	= 0.126	Mean of dep var	= 0.112

** Denotes a significance level of 5%.
* Denotes a significance level of 10%.

Table A3
Logit Estimations of the Ownership of Double Glazing:
A Comparison of Models

	ESTIMATED WITH SUB-SAMPLE					ESTIMATED WITH FULL SAMPLE		
	1		2			3		
	Structural Model		Reduced Form			Reduced Form		
Variable	β	s.e.	β	s.e.	Mean	β	s.e.	Mean
Ln Income	0.20	0.14	0.18	0.14	8.72	0.27	0.07 **	8.56
Perimeter	0.80	0.24 **	0.78	0.24 **	10.34	0.11	0.05 **	10.21
Area	-0.03	0.01 **	-0.03	0.01 **	111.05	-0.003	0.002 *	110.77
Head 26-39	-0.52	0.37	-0.53	0.37	0.31	0.00	0.16	0.28
Head 40-59	-0.11	0.38	-0.12	0.38	0.36	0.10	0.16	0.33
Head 60+	0.07	0.46	0.06	0.46	0.29	0.19	0.21	0.33
Pensioner	-0.43	0.34	-0.42	0.33	0.23	-0.19	0.15	0.27
Unemployed	-0.07	0.50	-0.09	0.50	0.02	-0.09	0.23	0.03
Unoccupied	-0.15	0.44	-0.15	0.44	0.04	-0.20	0.19	0.06
LA/HA	-2.56	0.27 **	-2.56	0.27 **	0.20	-2.24	0.11 **	0.31
PRented	-2.73	0.76 **	-2.73	0.76 **	0.03	-1.38	0.15 **	0.10
Semi-det	-0.03	0.23	-0.02	0.23	0.36	-0.16	0.10	0.30
Terraced	-0.77	0.25 **	-0.74	0.25 **	0.48	-0.51	0.11 **	0.39
Flat	-0.59	0.47	-0.56	0.47	0.04	-0.59	0.15 **	0.16
Electric						0.30	0.11 **	0.10
Other fuel						-0.25	0.09 **	0.18
Shared fuel						-0.28	0.49	0.01
No fuel						0.87	0.85	0.00
Midlands	0.09	0.19	0.10	0.19	0.21	-0.004	0.09	0.19
E Anglia	0.53	0.33	0.55	0.33 *	0.05	0.41	0.16 **	0.04
S East	0.72	0.21 **	0.73	0.21 **	0.15	0.63	0.10 **	0.14
London	0.79	0.20 **	0.79	0.20 **	0.17	0.64	0.10 **	0.17
West	0.29	0.29	0.31	0.29	0.06	0.49	0.11 **	0.10
Res 2<5yrs	0.25	0.23	0.24	0.23	0.20	0.05	0.11	0.19
Res 5<10yrs	0.47	0.24 *	0.46	0.24 *	0.19	0.27	0.11 **	0.18
Res 10<20yrs	0.44	0.24 *	0.42	0.24 *	0.22	0.47	0.11 **	0.20
Res 20+yrs	0.16	0.27	0.14	0.27	0.25	0.27	0.12 **	0.24
Move likely	-0.04	0.19	-0.04	0.19	0.17	-0.10	0.09	0.18
Built 1900-18	0.14	0.22	0.14	0.22	0.13	0.01	0.11	0.11
Built 1919-44	0.52	0.20 **	0.52	0.20 **	0.34	0.70	0.09 **	0.28
Built 1945-64	0.89	0.25 **	0.90	0.25 **	0.18	1.00	0.11 **	0.19
Built 1965+	0.62	0.28 **	0.63	0.28 **	0.09	1.00	0.13 **	0.11
CentHeat	0.73	0.19 **	0.66	0.17 **	0.71	0.78	0.08 **	0.64
Fuel consumption	-0.14	0.17						
Constant	-6.54	2.08 **	-7.11	1.97 **	1.00	-4.49	0.71 **	1.00

Model 1		Model 2		Model 3	
Number of obs	= 1294	Number of obs	= 1294	Number of obs	= 6395
$Chi^2(30)$	= 425.0	$Chi^2(29)$	= 424.3	$Chi^2(33)$	= 1866
'Pseudo' R^2	= 0.242	'Pseudo' R^2	= 0.242	'Pseudo' R^2	= 0.233
Mean of dep var	= 0.415	Mean of dep var	= 0.415	Mean of dep var	= 0.316

** Denotes a significance level of 5%.
* Denotes a significance level of 10%.

Table A4

Structural Model of the Ownership of Loft Insulation: Exogeneity Test

Variable	Consumption Equation β	Consumption Equation s.e.	Ownership Equation β	Ownership Equation s.e.	Mean
Ln Income	3.484	1.072 **	0.012	0.224	8.720
* LA/HA	-2.893	1.155 **			1.644
* PRented	-6.792	2.916 **			0.284
* CentHeat	-3.225	1.057 **			6.259
* Pensioner	-1.658	1.205			1.798
$(\text{Ln Income})^2$	-0.197	0.063 **			76.545
* LA/HA	0.173	0.069 **			13.692
* PRented	0.407	0.175 **			2.331
* CentHeat	0.190	0.063 **			55.689
* Pensioner	0.098	0.074			14.225
Perimeter	0.121	0.025 **	-0.021	0.241	10.343
Area	-0.002	0.001 **	-0.003	0.008	111.047
Head 26-39	0.013	0.062	0.636	0.437	0.314
Head 40-59	0.149	0.065 **	1.112	0.473 **	0.356
Head 60+	0.139	0.077 *	1.693	0.658 **	0.290
Pensioner	6.960	4.906	-1.040	0.538 *	0.228
Unemployed	0.129	0.077 *	-0.464	0.586	0.024
Unoccupied	-0.008	0.061	-0.668	0.445	0.043
LA/HA	12.031	4.795 **	0.026	0.283	0.199
PRented	28.143	12.077 **	-2.052	0.379 **	0.035
Semi-det	-0.082	0.040 **	0.401	0.402	0.360
Terraced	-0.173	0.042 **	-0.605	0.400	0.485
Flat	-0.133	0.071 *	-1.191	0.549 **	0.041
Midlands	-0.003	0.050	0.073	0.249	0.214
E Anglia	-0.256	0.104 **	-0.129	0.491	0.046
S East	-0.031	0.077	-0.308	0.298	0.149
London	-0.309	0.075 **	0.170	0.296	0.170
West	-0.137	0.097	-0.463	0.387	0.060
Res 2<5yrs	0.058	0.040	0.030	0.351	0.196
Res 5<10yrs	0.052	0.041	-0.292	0.352	0.195
Res 10<20yrs	0.103	0.041 **	-0.399	0.369	0.223
Res 20+yrs	0.106	0.045 **	-0.572	0.392	0.247
Move likely			0.141	0.255	0.167
Built 1900-18	-0.015	0.038	0.121	0.272	0.130
Built 1919-44	-0.030	0.033	0.084	0.254	0.339
Built 1945-64	-0.072	0.040 *	0.617	0.372 *	0.176
Built 1965+	-0.095	0.047 **	1.366	0.634 **	0.090
CentHeat	13.842	4.428 **	1.255	0.390 **	0.708
* Midlands	-0.026	0.063			0.128
* E Anglia	0.139	0.123			0.033
* West	0.070	0.112			0.046
* London	0.339	0.084 **			0.142
* S East	-0.029	0.086			0.124
NumKidsU5	0.096	0.024 **			0.219
NumKids5-10	0.055	0.023 **			0.234
NumKids11-16	0.044	0.020 **			0.267
WaterGas	0.199	0.042 **			0.800
CookGas	0.087	0.026 **			0.740
WaterTank	0.104	0.037 **			0.656
Constant	-10.395	4.516 **	3.546	3.461	1.000
Fuel consumption			-0.338	0.673	6.465
$\hat{u}_{2i}$			0.219	0.710	0.000

Number of obs	= 1294	Number of obs	= 1294
$F(48,1245)$	= 24.78	$\text{Chi}^2(31)$	= 188.5
R^2	= 0.487	'Pseudo' R^2	= 0.185
Mean of dep var	= 6.464	Mean of dep var	= 0.866

** Denotes a significance level of 5%.
* Denotes a significance level of 10%.

Table A5

Structural Model of the Ownership of Wall Insulation: Exogeneity Test

	Consumption Equation		Ownership Equation		
Variable	β̂	s.e.	β̂	s.e.	Mean
Ln Income	3.484	1.072 **	0.055	0.222	8.720
* LA/HA	-2.893	1.155 **			1.644
* PRented	-6.792	2.916 **			0.284
* CentHeat	-3.225	1.057 **			6.259
* Pensioner	-1.658	1.205			1.798
Ln Income^2	-0.197	0.063 **			76.545
* LA/HA	0.173	0.069 **			13.692
* PRented	0.407	0.175 **			2.331
* CentHeat	0.190	0.063 **			55.689
* Pensioner	0.098	0.074			14.225
Perimeter	0.121	0.025 **	-0.098	0.279	10.343
Area	-0.002	0.001 **	0.002	0.010	111.047
Head 26-39	0.013	0.062	0.053	0.581	0.314
Head 40-59	0.149	0.065 **	0.113	0.603	0.356
Head 60+	0.139	0.077 *	0.675	0.661	0.290
Pensioner	6.960	4.906	-0.781	0.397 **	0.228
Unemployed	0.129	0.077 *	-1.353	1.058	0.024
Unoccupied	-0.008	0.061	-0.081	0.473	0.043
LA/HA	12.031	4.795 **	-0.265	0.269	0.199
PRented	28.143	12.077 **	0.120	0.647	0.035
Semi-det	-0.082	0.040 **	-0.584	0.286 **	0.360
Terraced	-0.173	0.042 **	-0.514	0.330	0.485
Flat	-0.133	0.071 *	-0.584	0.597	0.041
Midlands	-0.003	0.050	-0.038	0.237	0.214
E Anglia	-0.256	0.104 **	-0.313	0.446	0.046
S East	-0.031	0.077	0.024	0.255	0.149
London	-0.309	0.075 **	-1.030	0.344 **	0.170
West	-0.137	0.097	-0.013	0.366	0.060
Res 2<5yrs	0.058	0.040	0.216	0.356	0.196
Res 5<10yrs	0.052	0.041	0.630	0.353 *	0.195
Res 10<20yrs	0.103	0.041 **	0.658	0.360 *	0.223
Res 20+yrs	0.106	0.045 **	0.255	0.401	0.247
Move likely			-0.419	0.273	0.167
Built 1900-18	-0.015	0.038	0.086	0.346	0.130
Built 1919-44	-0.030	0.033	0.188	0.290	0.339
Built 1945-64	-0.072	0.040 *	0.860	0.310 **	0.176
Built 1965+	-0.095	0.047 **	0.781	0.341 **	0.090
CentHeat	13.842	4.428 **	1.115	0.458 **	0.708
* Midlands	-0.026	0.063			0.128
* E Anglia	0.139	0.123			0.033
* West	0.070	0.112			0.046
* London	0.339	0.084 **			0.142
* S East	-0.029	0.086			0.124
NumKidsU5	0.096	0.024 **			0.219
NumKids5-10	0.055	0.023 **			0.234
NumKids11-16	0.044	0.020 **			0.267
WaterGas	0.199	0.042 **			0.800
CookGas	0.087	0.026 **			0.740
WaterTank	0.104	0.037 **			0.656
Constant	-10.395	4.516 **	-0.290	3.969	1.000
Fuel consumption			-0.352	0.800	6.465
$\hat{u}_{2i}$			-0.070	0.840	0.000

Number of obs	= 1294	Number of obs	= 1294
F(48,1245)	= 24.78	Chi^2(31)	= 93.03
R^2	= 0.487	'Pseudo' R^2	= 0.095
Mean of dep var	= 6.464	Mean of dep var	= 0.126

** Denotes a significance level of 5%.
* Denotes a significance level of 10%.

Table A6

Structural Model of the Ownership of Double Glazing: Exogeneity Test

	Consumption Equation		Ownership Equation		
Variable	β	s.e.	β	s.e.	Mean
Ln Income	3.484	1.072 **	0.130	0.160	8.720
* LA/HA	-2.893	1.155 **			1.644
* PRented	-6.792	2.916 **			0.284
* CentHeat	-3.225	1.057 **			6.259
* Pensioner	-1.658	1.205			1.798
Ln $Income^2$	-0.197	0.063 **			76.545
* LA/HA	0.173	0.069 **			13.692
* PRented	0.407	0.175 **			2.331
* CentHeat	0.190	0.063 **			55.689
* Pensioner	0.098	0.074			14.225
Perimeter	0.121	0.025 **	0.736	0.250 **	10.343
Area	-0.002	0.001 **	-0.029	0.010 **	111.047
Head 26-39	0.013	0.062	-0.541	0.365	0.314
Head 40-59	0.149	0.065 **	-0.168	0.384	0.356
Head 60+	0.139	0.077 *	0.027	0.463	0.290
Pensioner	6.960	4.906	-0.421	0.335	0.228
Unemployed	0.129	0.077 *	-0.146	0.503	0.024
Unoccupied	-0.008	0.061	-0.151	0.436	0.043
LA/HA	12.031	4.795 **	-2.535	0.271 **	0.199
PRented	28.143	12.077 **	-2.721	0.759 **	0.035
Semi-det	-0.082	0.040 **	0.010	0.239	0.360
Terraced	-0.173	0.042 **	-0.683	0.263 **	0.485
Flat	-0.133	0.071 *	-0.516	0.475	0.041
Midlands	-0.003	0.050	0.095	0.191	0.214
E Anglia	-0.256	0.104 **	0.610	0.346 *	0.046
S East	-0.031	0.077	0.745	0.212 **	0.149
London	-0.309	0.075 **	0.804	0.205 **	0.170
West	-0.137	0.097	0.341	0.299	0.060
Res 2<5yrs	0.058	0.040	0.210	0.236	0.196
Res 5<10yrs	0.052	0.041	0.431	0.245 *	0.195
Res 10<20yrs	0.103	0.041 **	0.383	0.251	0.223
Res 20+yrs	0.106	0.045 **	0.105	0.276	0.247
Move likely			-0.037	0.186	0.167
Built 1900-18	-0.015	0.038	0.140	0.220	0.130
Built 1919-44	-0.030	0.033	0.523	0.198 **	0.339
Built 1945-64	-0.072	0.040 *	0.924	0.250 **	0.176
Built 1965+	-0.095	0.047 **	0.679	0.286 **	0.090
CentHeat	13.842	4.428 **	0.474	0.325	0.708
* Midlands	-0.026	0.063			0.128
* E Anglia	0.139	0.123			0.033
* West	0.070	0.112			0.046
* London	0.339	0.084 **			0.142
* S East	-0.029	0.086			0.124
NumKidsU5	0.096	0.024 **			0.219
NumKids5-10	0.055	0.023 **			0.234
NumKids11-16	0.044	0.020 **			0.267
WaterGas	0.199	0.042 **			0.800
CookGas	0.087	0.026 **			0.740
WaterTank	0.104	0.037 **			0.656
Constant	-10.395	4.516 **	-8.616	2.991 **	1.000
Fuel consumption			0.384	0.568	6.465
$\hat{u}_{2i}$			-0.577	0.595	0.000

Number of obs	= 1294	Number of obs	= 1294
F(48,1245)	= 24.78	Chi^2(31)	= 425.9
R^2	= 0.487	'Pseudo' R^2	= 0.243
Mean of dep var	= 6.464	Mean of dep var	= 0.415

** Denotes a significance level of 5%.
* Denotes a significance level of 10%.

Table A7

Logit Estimation of Wall Insulation:
Models Estimated on the Full Sample, and on a Sample of Post-1945 Dwellings

	1			2		
	Full Sample Estimation			Post-1945 dwellings (cavity-walled)		
Variable	β	s.e.	Mean	β	s.e.	Mean
Ln Income	0.337	0.095 **	8.563	0.491	0.160 **	8.444
Perimeter	-0.102	0.054 *	10.206	-0.243	0.110 **	9.550
Area	0.002	0.002	110.705	0.006	0.003 **	95.539
Head 26-39	0.140	0.231	0.280	-0.099	0.397	0.236
Head 40-59	0.247	0.236	0.329	0.009	0.402	0.326
Head 60+	0.476	0.275 *	0.326	0.296	0.447	0.381
Pensioner	-0.379	0.191 **	0.266	-0.353	0.285	0.305
Unemployed	0.182	0.264	0.030	0.682	0.386 *	0.029
Unoccupied	-0.274	0.239	0.057	-0.133	0.375	0.071
LA/HA	-0.098	0.120	0.305	-0.245	0.182	0.602
PRented	-0.360	0.199 *	0.097	-0.993	0.566 *	0.021
Semi-det	-0.561	0.124 **	0.305	-0.737	0.204 **	0.334
Terraced	-0.706	0.137 **	0.395	-1.064	0.234 **	0.258
Flat	-1.158	0.206 **	0.164	-1.538	0.311 **	0.288
Electric	-0.083	0.157	0.103	0.058	0.238	0.128
Other fuel	0.049	0.112	0.180	-0.094	0.191	0.164
Shared fuel	-0.241	0.492	0.013	-0.011	0.513	0.040
Midlands	0.032	0.117	0.191	0.156	0.188	0.206
E Anglia	0.160	0.193	0.044	0.115	0.326	0.040
S East	0.255	0.122 **	0.139	0.395	0.199 **	0.152
London	-0.816	0.175 **	0.167	-0.649	0.316 **	0.147
West	0.377	0.136 **	0.104	0.845	0.210 **	0.116
Res 2<5 yrs	0.133	0.143	0.189	0.014	0.249	0.193
Res 5<10yrs	0.461	0.141 **	0.174	0.518	0.242 **	0.178
Res 10<20yrs	0.297	0.145 **	0.205	0.370	0.240	0.253
Res 20+yrs	0.218	0.161	0.238	0.441	0.264 *	0.218
Move likely	-0.137	0.119	0.184	-0.153	0.203	0.161
Built 1900-18	-0.225	0.176	0.108			
Built 1919-44	0.023	0.129	0.283			
Built 1945-64	0.562	0.137 **	0.186			
Built 1965+	0.769	0.147 **	0.110	0.293	0.153 *	0.372
CentHeat	0.581	0.108 **	0.645	0.303	0.180 *	0.704
Constant	-4.547	0.935 **	1.000	-3.827	1.624 **	1.000

	Number of obs	= 6374	Number of obs	= 1884
	$Chi^2(32)$	= 400.8	$Chi^2(29)$	= 192.4
	'Pseudo' R^2	= 0.090	'Pseudo' R^2	= 0.116
	Mean of dep var	= 0.112	Mean of dep var	= 0.161

** Denotes a significance level of 5%.
* Denotes a significance level of 10%.

Table A8
Logit Estimation of Double Glazing:
Ownership of Any Double Glazing, and Ownership of Full Double Glazing

	1			2		
	Any Windows Double Glazed			Entire Dwelling Double Glazed		
Variable	β	s.e.	Mean	β	s.e.	Mean
Ln Income	0.271	0.067 **	8.563	0.150	0.093	8.564
Perimeter	0.110	0.052 **	10.208	-0.072	0.052	10.210
Area	-0.003	0.002 *	110.77	0.001	0.001	110.81
Head 26-39	0.001	0.160	0.280	-0.060	0.235	0.280
Head 40-59	0.104	0.164	0.330	0.143	0.242	0.329
Head 60+	0.192	0.205	0.325	0.330	0.288	0.326
Pensioner	-0.186	0.154	0.265	-0.208	0.202	0.265
Unemployed	-0.092	0.229	0.025	-0.145	0.354	0.025
Unoccupied	-0.204	0.187	0.057	-0.557	0.330 *	0.057
LA/HA	-2.237	0.107 **	0.305	-2.126	0.169 **	0.305
PRented	-1.383	0.147 **	0.097	-1.235	0.255 **	0.097
Semi-det	-0.162	0.103	0.305	-0.002	0.131	0.305
Terraced	-0.512	0.110 **	0.394	0.006	0.146	0.394
Flat	-0.586	0.153 **	0.164	-0.374	0.219 *	0.164
Electric	0.298	0.114 **	0.103	0.324	0.157 **	0.103
Other fuel	-0.252	0.092 **	0.180	-0.071	0.128	0.180
Shared fuel	-0.277	0.492	0.013	-0.432	0.626	0.013
No fuel[a]	0.872	0.847	0.001			
Midlands	-0.004	0.093	0.192	-0.358	0.139 **	0.192
E Anglia	0.405	0.159 **	0.043	-0.018	0.224	0.043
S East	0.634	0.099 **	0.139	0.417	0.127 **	0.139
London	0.635	0.100 **	0.167	0.496	0.133 **	0.167
West	0.489	0.112 **	0.104	0.076	0.155	0.104
Res 2<5yrs	0.046	0.105	0.189	-0.075	0.145	0.190
Res 5<10yrs	0.272	0.109 **	0.175	-0.044	0.150	0.175
Res 10<20yrs	0.468	0.109 **	0.205	0.055	0.146	0.205
Res 20+yrs	0.272	0.121 **	0.237	-0.025	0.164	0.237
Move Likely	-0.103	0.087	0.184	-0.095	0.122	0.184
Built 1900-18	0.011	0.108	0.109	-0.172	0.180	0.109
Built 1919-44	0.700	0.092 **	0.282	0.778	0.128 **	0.282
Built 1945-64	0.999	0.112 **	0.185	1.232	0.146 **	0.186
Built 1965+	0.996	0.128 **	0.109	1.201	0.163 **	0.110
CentHeat	0.780	0.078 **	0.645	0.753	0.122 **	0.646
Constant	-4.489	0.709 **	1.000	-3.675	0.932 **	1.000
	Number of obs		6395	Number of obs		6386
	$Chi^2(33)$		1866	$Chi^2(32)$		634.0
	'Pseudo' R^2		0.233	'Pseudo' R^2		0.147
	Mean of dep var		0.316	Mean of dep var		0.106

** Denotes a significance level of 5%.
* Denotes a significance level of 10%.
[a]None of the nine households which are recorded as using no fuel for heating have the entire dwelling double glazed. All nine households have therefore been dropped from the sample in the estimation of the possession of full double glazing. This accounts for the difference in sample size between the two models.

Table A9
A Description of the Explanatory Variables

Variable name	Description
Ln Income	The log of income. Income is as defined in Chapter 6.
Perimeter	The square root of the area of the dwelling. This is an approximation of the perimeter, which is a proxy for heat loss in the dwelling.
Area	The area of the dwelling (equal to the square of the perimeter).
Head 26-39	Dummy variable coded one if the head of the household is 26 - 39 years old.
Head 40-59	Dummy variable coded one if the head of the household is 40 - 59 years old.
Head 60+	Dummy variable coded one if the head of the household is over 60 years old.
Pensioner	Dummy variable coded one if the head of household is a pensioner. Note: if this is coded one, Head 60+ must be coded one.
Unemployed	Dummy variable coded one if the head of the household is unemployed for less than one year.
Unoccupied	Dummy variable coded one if the head of the household is unemployed for one year or more.
LA/HA	Dummy variable coded one if household is local authority or housing association tenant.
PRented	Dummy variable coded one if household is private tenant.
Semi-det	Dummy variable coded one if the dwelling is semi-detached.
Terraced	Dummy variable coded one if the dwelling is terraced.
Flat	Dummy variable coded one if the dwelling is a flat.
Electric	Dummy variable coded one if electricity is the main fuel used for space heating.
Other fuel	Dummy variable coded one if fuels other than gas or electricity are the main fuel used for space heating.
Shared fuel	Dummy variable coded one if shared fuel is the main fuel used for space heating.
No fuel	Dummy variable coded one if no fuel is used for space heating.
Midlands	Dummy variable coded one if household resides in the Midlands.
E Anglia	Dummy variable coded one if household resides in East Anglia.
S East	Dummy variable coded one if household resides in the South-East, but not London.
London	Dummy variable coded one if household resides in London.
West	Dummy variable coded one if household resides in the West Country.
Res 2<5yrs	Dummy variable coded one if household has resided in dwelling for at least 2 years, but less than 5.
Res 5<10yrs	Dummy variable coded one if household has resided in dwelling for at least 5 years but less than 10.
Res 10<20yrs	Dummy variable coded one if household has resided in dwelling for at least 10 years, but less than 20.
Res 20+yrs	Dummy variable coded one if household has resided in dwelling for 20 years or longer.
Move likely	Dummy variable coded one if household thinks it is likely to move in the next two years.
Built 1900-18	Dummy variable coded one if dwelling was built between 1900 and 1918.
Built 1919-44	Dummy variable coded one if dwelling was built between 1919 and 1944.
Built 1945-64	Dummy variable coded one if dwelling was built between 1945 and 1964.
Built 1965+	Dummy variable coded one if dwelling was built in 1965 or later.
CentHeat	Dummy variable coded one if the household has central heating.
Fuel consumption	Log of annual fuel consumption by the household measured in therms.
NumKidsU5	Number of children under 5 in the household.
NumKids5-10	Number of children between 5 and 10 in the household.
NumKids11-16	Number of children between 11 and 16 in the household.
WaterGas	Dummy variable coded one if the household uses gas as its main fuel to heat water.
CookGas	Dummy variable coded one if the household uses gas as its main cooking fuel.
WaterTank	Dummy variable coded one if the household has water tank insulation and uses gas as its main fuel to heat water.

References

Barnett, R. (1986), 'An economic appraisal of local energy conservation schemes', *Energy Policy*, pp. 425-36.

Blundell, R. and Preston, I. (1991), 'The distinction between income and consumption in the measurement of household welfare', Institute for Fiscal Studies, Working Paper no. 91/1.

Boardman, B. (1991), *Fuel Poverty: From Cold Homes to Affordable Wealth*, London: Belhaven Press.

Davies, A. J. and Weber, G. (1991), 'Credit and British consumers: some micro evidence', *Fiscal Studies*, vol. 12, no. 2, pp. 61-84.

Hausman, J. A. (1979), 'Individual discount rates and the purchase and utilization of energy-using durables', *The Bell Journal of Economics*, vol. 10, pp. 33-54.

Hedges, A. (1991), *Attitudes to Energy Conservation in the Home*, London: HMSO.

Henderson, G. and Shorrock, L. (1989a), *Domestic Energy Fact File*, Watford: Building Research Establishment.

Henderson, G. and Shorrock, L. (1989b), *Energy Use in Buildings and Carbon Dioxide Emissions*, Watford: Building Research Establishment.

Horowitz, M. J. and Haeri, H. (1990), 'Economic efficiency vs. energy efficiency: do model conservation standards make good sense?', *Energy Economics*, pp. 122-31.

Hutton, S. et al. (1985), *Energy Efficiency in Low Income Households: An Evaluation of Local Insulation Projects*, Energy Efficiency Series 4, London: HMSO.

Jochem, E. and Gruber, E. (1990), 'Obstacles to rational electricity use and measures to alleviate them', *Energy Policy*, pp. 340-50.

Laquatra, J. (1986), 'Housing market capitalization of thermal integrity', *Energy Economics*, pp. 134-8.

McFadden, D. (1974), 'The measurement of urban travel demand', *Journal of Public Economics*, vol. 3, pp. 303-28.

Pezzey, J. (1984), *An Economic Assessment of some Energy Conservation Measures in Housing and Other Buildings*, Watford: Building Research Establishment.

Smith, R. J. and Blundell, R. W. (1986), 'An exogeneity test for a simultaneous equation tobit model with an application to labour supply', *Econometrica*, vol. 54, pp. 679-85.

Weber, G. (1990), 'Earnings-related borrowing restrictions: empirical evidence from a pseudo-panel for the UK', University College London, Discussion Paper in Economics no. 90-17.