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The macro-economic rebound effect and the UK economy

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Abstract

This paper examines the macroeconomic rebound effect for the UK economy arising from energy efficiency policies 2000–2010 using the macroeconomic model, MDM-E3. The literature distinguishes between three types of rebound effect: direct, indirect and economy-wide. The macroeconomic rebound effect considered here is the combination of the indirect and economy-wide effects. Policies for the domestic, business, commercial and public, and transport sectors of the economy are analysed for 2000–2010. Overall, the policies lead to a saving of about 8% of the energy, which would otherwise have been used and a reduction in CO_2 emissions of 10% (or 14 mtC) by 2010. There are also favourable macroeconomic effects: lower inflation and higher growth. We find that the macroeconomic rebound effect arising from UK energy efficiency policies for the period 2000–2010 is around 11% by 2010, averaged across sectors of the economy. When this is added to the (assumed) direct rebound effect of around 15%, this gives a total rebound effect of around 26% arising from these policies. Thus, the findings of the study support the argument that energy efficiency improvements for both consumers and producers, stimulated by policy incentives, will lead to significant reductions in energy demand and hence in greenhouse gas emissions.

JEL classification: E12; O52; Q43

Keywords: Rebound effect; Energy efficiency; Top-down/bottom-up modelling

1. Introduction

This article explores the macro-economic rebound effect for the UK economy from energy efficiency policies and programmes using a well-established and highly detailed macroeconomic model of the UK economy.[1]

The rebound effect refers to the idea that some or all of the expected reductions in energy consumption as a result of energy efficiency improvements are offset by an increasing demand for energy services, arising from reductions in the effective price of energy services resulting from those improvements. As policies to stimulate energy efficiency improvements are a key part of national and international climate change policies (see Geller et al., 2006), the likely magnitude of any rebound effect is of great importance to assessing the effectiveness of those policies. However, the magnitude, and even the definition and the scope, of rebound effects have been the subject of heated debate since early exchanges in this journal between Len Brookes (Brookes, 1990) and Michael Grubb (Grubb, 1990).

Recent literature distinguishes between three types of rebound effect (Greening et al., 2000):

- *Direct rebound effects*: Improved energy efficiency for a particular energy service will decrease the effective price of that service and should therefore lead to an increase

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[1]The results reported here are an extension of the study of the macroeconomic rebound effects of UK energy efficiency policies undertaken by the authors and colleagues for the UK Department for Environment, Food and Rural Affairs (Defra). The full findings of that study are reported in the final report (Cambridge Centre for Climate Change Mitigation Research 4CMR et al., 2006) which is available on the Defra website.

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in consumption of that service. This will tend to offset the expected reduction in energy consumption provided by the efficiency improvement.

- *Indirect rebound effects*: For consumers, the lower effective price of the energy service will lead to changes in the demand for other goods and services. To the extent that these require energy for their provision, there will be indirect effects on aggregate energy consumption.
- *Economy-wide rebound effects*: A fall in the real price of energy services will reduce the price of intermediate and final goods throughout the economy, leading to a series of price and quantity adjustments, with energy-intensive goods and sectors gaining at the expense of less energy-intensive ones. Energy efficiency improvements may also increase economic growth, which should itself increase energy consumption.

Of particular interest for energy and climate policy is the magnitude of the macro-economic rebound effect, which we take to cover the indirect and economy-wide rebound effects. The Khazzoom–Brookes postulate (Brookes, 1990; Saunders, 1992, 2000) is an interpretation of the rebound effect at the macroeconomic level suggesting that the aggregate energy saving from energy efficiency measures might be offset by associated increases in energy demand.

The main objective of the paper is to contribute to the evidence on this issue by examining the macro-economic rebound effect for the UK economy from energy efficiency policies and programmes, using an energy–environment–economy (E3) model of the UK economy. It should be noted that the paper focuses on the macroeconomic implications of energy efficiency policies and programmes for final users of energy, and does not provide an evaluation of their likely effectiveness at a micro level.

Section 2 of the paper provides a brief review of the debates on the macro-economic rebound effect in relation to energy and climate policy. Section 3 describes the approach taken here to modelling the macro-economic rebound effect. Section 4 describes the UK energy efficiency policies incorporated into this modelling and the scenarios used. Section 5 describes the results, including the overall impacts of energy efficiency policies on energy demand, economic activity and CO_2 emissions, and the sources and magnitude of the macro-economic rebound effect. Section 6 provides some conclusions.

2. Literature review

There is already an extensive literature on the rebound effect which has been summarised by Herring (Herring, 1998, 2004), in a special issue of *Energy Policy* (Schipper and Grubb, 2000), by Vikström (2004), by Grepperud and Rasmussen (2004), in (International Energy Agency, 2005), and by a current project of the UK Energy Research Centre (UKERC) (Sorrell and Dimitropoulos, 2005). Therefore only the main outlines of the debate will be reviewed here.

While the existence of the direct rebound effect is widely accepted, and its magnitude is often estimated, there is much greater conceptual and empirical controversy over the magnitude of the rebound effect at the macro-level. This is because of the difficulty of determining empirically its impact given the host of factors that affect national energy consumption.

Debate broke out in the energy economics literature in the early 1990s as to the likely effectiveness of energy efficiency policies in contributing to greenhouse gas (GHG) emissions reductions, given the potential for rebound at the macroeconomic level. Despite further studies in the intervening period, the terms of the debate have changed little since these early exchanges.

Both sides of the debate acknowledge that the issue was first raised by British economist William Stanley Jevons in his 1865 book, 'The Coal Question' (Jevons, 1865/1905). Jevons argued: '*It is a confusion of ideas to suppose that the economical use of fuel is equivalent to diminished consumption. The very contrary is the truth*' ….'*The reduction of the consumption of coal, per ton of iron, to less than one third of its former amount, was followed, in Scotland, by a ten fold increase in total consumption, between the years 1830 and 1863, not to speak of the indirect effect of cheap iron in accelerating other coal-consuming branches of industry*.' In other words, an increase in the fuel efficiency of iron production contributed to an increased (rather than reduced) production of iron, and hence to a dramatic increase in the consumption of coal.

This argument was taken up by Daniel Khazzoom in the US and Len Brookes in the UK. Brookes (1990) argued that significant increases in energy productivity are observed historically, i.e. less energy is needed per unit of output, but that substitution of energy for labour and capital has generally led to more rapid improvements in total factor productivity and hence growth in overall output, resulting in increases in total energy consumption. He concluded that efforts to stimulate energy efficiency improvements could lead to increases rather than decreases in GHG emissions, without accompanying price measures.

The counter position was put by Amory Lovins in the US and Michael Grubb in the UK. Grubb (1990) argued that there are significant differences between 'naturally occurring' energy efficiency improvements, i.e. those resulting from normal economic imperatives to reduce costs of production and find new markets, and energy efficiency improvements stimulated by direct incentives. He argued that the latter could focus on areas dominated by market failures/barriers, where the implicit price falls arising from efficiency improvements would have little effect on activity levels. The existence of such barriers to the take-up of cost effective energy efficiency improvements has been widely argued and generally, though not universally, accepted.

Both sides in this debate agree that energy-saving technological change contributes to economic growth by stimulating 'structural changes' in economic activity, i.e. new activities that were not previously economically viable. However, Grubb and Lovins argue that energy efficiency policies primarily address market failures/barriers, which prevent currently most energy-efficient technology or system being used. Empirical evidence, such as that from the Carbon Trust (2005), suggests that a high level of cost-effective energy efficiency improvements can be found and implemented when attention is focussed on their potential by policy incentives. Hence, this debate raises the question: are (policy-) induced energy efficiency improvements mainly reducing economic inefficiencies through overcoming market barriers, or are they also likely to stimulate significant increased economic activity?

3. Modelling the macroeconomic rebound effect

The macroeconomic rebound effect arising from UK energy efficiency policies and programmes is investigated here using MDM-E3, a sectoral dynamic macroeconomic model of the UK economy[2] which has been developed to allow for E3 interactions (Barker et al., 1995; Barker et al., 2005). The model contains 51 production sectors, which enables a more accurate representation of the effects of policies than is common in most macroeconomic modelling approaches. Though it also includes a sub-model of the electricity generation and supply sector, this is less detailed than that in bottom-up energy systems models such as MARKAL. However, such energy systems models typically have no or limited representation of economy-wide interactions. These are captured in MDM-E3 through the interactions between the different sectors in the model, with input–output and econometric modelling allowing for complex interactions between output, employment, consumption, investment, trade, prices and wages, without assuming that resources are used at full economic efficiency.

For each of the main stochastic variables, e.g. employment, a set of equations is estimated on annual data covering 51 sectors and 12 regions using co-integrating techniques, which allow the long-term relationship to be identified in addition to the short-term, dynamic one. Typically the volume equations (employment, consumption, investment, trade) explain changes in terms of current and lagged changes in activity levels, relative prices and capacity utilisation, and the price equations (for wage rates, output and trade prices) explain inflation in terms of current and lagged changes in unit costs and utilisation of capacity. The equations and identities are solved iteratively for each year, assuming adaptive expectations, until a consistent solution is obtained. The economy aggregates, such as GDP, are found by summation. This enables representation of the wider macroeconomic impacts of policies focused on particular sectors, including rebound effects.

The modelling undertaken in this study required the specification of scenarios to reflect the set of UK energy efficiency policies and programmes for the domestic, business, commercial and public, and transport sectors of the economy for the period 2000–2010. An inventory was prepared of the characteristics of the energy efficiency policies, measures and programmes relevant to understanding, analysing and modelling their effects. These characteristics have included sector, social group, scale and timing. The *direct effects* on energy savings and costs of these measures were estimated from the literature and engineering studies, principally the evaluation of UK energy efficiency policies and programmes conducted by FES and PSI (FES/PSI, 2005), and the evaluation of the voluntary agreement package by the Department for Transport (DfT, 2005). These evaluations include the direct effects on energy savings, the costs to the exchequer, firms and individuals where available, and estimates of any known direct rebound effects, as defined above, also referred to as 'comfort taking.' These estimates are incorporated exogenously into the macro-economic modelling.

A set of initial reductions in net energy demand brought about by energy efficiency programmes is aggregated in terms of the model's classification and imposed on selected fuel users. The effects of the energy efficiency policies are calculated by comparing model solutions 2000–2100 with and without the policies. Scenarios were developed to allow the calculation of macroeconomic rebound effects by modelling final energy demand by 13 fuel user groups, aggregated to six sectors: energy-intensive industries (basic metals, minerals and chemicals), other industry, road transport, air transport, other final uses (commerce and public sector) and households (dwellings). The base case for the modelling includes present and committed energy efficiency policies for the period 2000–2010, including key assumptions (oil price, the carbon trading price from the EU Emissions Trading Scheme, ETS). A reference case was constructed for this period without energy efficiency policies, but including the EU ETS, which is not regarded as an energy efficiency policy. The fuel price assumptions were based on the DTI projections from February 2006 (DTI, 2006).

The macroeconomic rebound effect is the response of the economy (in terms of energy demand) stimulated through indirect and economy-wide effects by the initial energy savings arising from energy efficiency policies. In the model, the initial effects spread from the energy-using sectors throughout the rest of the economy. MDM-E3 automatically incorporates the macroeconomic and indirect effects through the input–output structure of the model. The macroeconomic rebound effects are calculated by taking the difference between the energy saving projected by the model, taking into account the indirect effects

[2]The Cambridge Multisectoral Dynamic Model (MDM-E3) (Barker and Peterson, 1987) is an econometric simulation model, which allows for varying retunes to scale and degrees of competition depending on estimated parameters. Bach et al. (2002) apply a model for Germany using a similar approach. Version MDM95, with 51 industrial sectors, was used for this paper; the current version, MDM01, has 41 industrial sectors.

throughout the economy, and the expected *net* sectoral energy saving (after allowing for the direct rebound effect) projected from energy-engineering studies for the policies. This difference is then expressed as a percentage of the expected *gross* energy saving from these studies.

In the case of extra energy saving in the household sector, the reduction in expenditure on fuels (assuming that fuel prices are unchanged) implies an increase in the real income of consumers. These effects are modelled by assuming consumers initially maintain the level of energy services received from the fuels, i.e. cut actual spending to receive the same services; however the further response is more complicated. We assume that they behave (1) *as if* fuel prices had fallen, so that they substitute back towards fuels, depending on their responses to lower effective prices, and (2) *as if* they had an increase in real income so that they increase spending on energy and other activities, depending on estimated income elasticities. For (2) the saving ratio is changed so that real expenditures rise by the appropriate amount. The higher consumers' expenditure on all goods and services, especially energy-intensive ones such as air transport, then raise energy use more generally.

The effect of energy saving in production is to reduce the costs of industrial energy use, so leading to reductions in prices and increases in profits of the industries working more efficiently. These lower prices are then passed on to reduce costs for other industries. The process gives rise to a rebound effect in that the initial savings are (partially) offset by increases in energy demands, due to higher demands for the outputs of the industries that have improved their energy efficiency and so reduced their energy costs. There are substitution effects – more energy use and less labour use, depending on estimated price/wage elasticities of energy/labour demand; and effects of an overall reduction in unit costs of production on prices and hence on general demand for products.

The lower costs will also be passed on to final consumers, depending on the price behaviour of the industries. Consumers will substitute spending towards the lower-priced products. Higher consumer and labour demand will increase output (and GDP) more generally and hence lead to higher energy demand.

4. Description of policies and scenarios

4.1. Policies

A set of energy efficiency policies were incorporated in the 2000 Climate Change Programme (Defra 2000, 2006), which set out a range of measures to achieve reductions in GHG emissions, with a view to cutting carbon emissions by 20% from 1990 levels by 2010. The policies relate to the household sector, the business and public sectors, and the transport sector. The target was confirmed in the 2003 Energy White Paper (DTI, 2003) and the policies to achieve this were further elaborated in the 2004 Energy Efficiency Action Plan (Defra, 2004). The majority of these additional policies are aimed at incentivising energy efficiency improvements. It is the macro-economic rebound effect arising from all these energy efficiency policy measures that it is assessed in this article.

4.2. Scenarios

The Reference Case is constructed to establish a counter-factual history of the UK economy for the period 2000–2010 without the impact of the additional energy efficiency policies implemented over this period. It is a fully dynamic solution of the model over the period, given the year-by-year profile of exogenous variables such as other countries' output and prices, exchange rates, interest rates and fiscal policies in general. It includes the impact of UK energy policy measures which are not explicitly targeted at energy efficiency, including the Climate Change Levy itself (but not the associated Climate Change Agreements, CCAs, which are treated as a key industrial component of the energy efficiency policies), the Fuel Duty escalator to 1999, and the delivery of the 10% renewable electricity generation target by 2010. It is thus close to the baseline scenario under the 2000 UK Climate Change Programme (Defra 2000, 2006), with the main difference being that the Reference Case includes the impacts of the UK and EU Emissions Trading Schemes.

The Base Case is an alternative fully dynamic solution, but including the sectoral effects on energy use, year by year 2000–2010, of all the current and committed UK energy efficiency policies for the domestic, business, commercial and transport sectors (Defra 2004; Defra 2000, 2006), including the explicit effects of the CCAs. The difference between the Base Case and the Reference Case thus gives a dynamic estimate of the impact of these policies on the UK economy, and will enable calculation of the amount by which the original estimated energy saving of the policies is reduced through the rebound effect.

Differences between the Reference and Base scenarios are used to assess the impacts of energy efficiency policies on energy demand and CO_2 emissions under the different scenario assumptions, taking into account the macroeconomic effects estimated using the model. By comparing these with the imposed estimates for energy and CO_2 saving from the earlier evaluation, which did not take the macroeconomic effects into account, estimates of the magnitude of the macroeconomic rebound effect on energy demand and CO_2 emissions are calculated.

4.3. Scenario assumptions

Within each scenario, the effects of the relevant policy measures are introduced into the model on an annual basis. This is done by including the projected direct energy saving resulting from actions taken as a result of that policy measure, taking into account any projected direct rebound effect, so-called 'comfort taking.' The projected direct energy and CO_2 emissions savings in 2010, shown in

Table 1 (allowing for the direct rebound effects discussed below) are used as inputs to the modelling. The table also converts these projected savings to the percentage of the total sectoral energy use and total sectoral emissions, respectively, to enable an approximate comparison of the strength of each policy.

The direct rebound effects by sector in energy terms are derived by applying the assumed rebound percentages to the gross energy savings from the sector. There are two broad sectors for which these direct rebound effects have been empirically estimated in the evaluations of UK energy efficiency policies: the transport sector, at 25% and the household sector at 28% by 2005 and 23% by 2010. The household sector shows a high direct rebound effect in the early years, primarily due to the 75% direct rebound assumed for the Warm Front programme (its primary aim is to help alleviate fuel poverty by providing energy efficiency measures to the most vulnerable households.) No value for the direct rebound for industrial or commercial sectors was taken, as no estimate has been made. However, there are good reasons for expecting the direct rebound effects to be small or negligible for these sectors. In the case of buildings, indoor temperatures are both conventionally and legally within acceptable ranges, and these ranges seem unlikely to change in response to energy efficiency measures. In the case of energy-intensive processes, the extra efficiency takes the form of lower unit costs and the rebound effects are the indirect effects of the lower costs on sales to other industries and exports, which we capture in the modelling. The assumed direct rebound effect, averaged across all sectors is 14–15%.

The assumptions used in the modelling for oil, coal and gas prices are shown in Table 2.

Table 2
UK fuel price and EU ETS allowance price assumptions, base case, 2002–2010

	2002	2005	2010
Current prices			
Oil ($/bl)	25	56	40
EU ETS allowance price (€/tCO_2)	0	18	32
1995 prices			
Oil ($/bl)	23	47	29
Coal (£/tonne)	27	28	18
Gas (*p*/kWh)	1	1	1
Gas (*p*/therm)	18	30	21

Note: These assumptions correspond to the midpoint of the DTI UEP February 2006 central fuel price assumptions, converted to units as shown in the table.
Source: Cambridge Econometrics, DTI.
Ref.: MDM95r9 C42Br9.

Table 1
Projected direct energy and CO_2 emissions savings[a] in 2010 for UK energy efficiency policies/measures used in this study as inputs to the modelling

Target sector	Policy/measure	Projected energy savings in 2010 (1000 GWh)	% of total sectoral energy use[b]	Projected CO_2 savings in 2010 (MtC)	% of total sectoral emissions[c]
Domestic	Building Regs '02	23.2	4.1	1.2	3.1
	Building Regs '05	16.3	2.9	0.8	2.1
	EEC[d] 2002–11	21.4	3.8	1.8	4.7
	NI-EEL	0.9	0.2	0.1	0.3
	Warm front	3.9	0.7	0.3	0.7
	Community energy	0.3	0.1	0.0	0.0
	Appliance standards and labelling	7.0	1.2	0.6	1.6
Business	CCAs	43.4	9.1	2.5	4.5
	CT—reduce emissions	17.7	6.2	1.3	2.3
	CT—low carbon technology	1.8	n/a	0.1	n/a
Commercial and public sector	Building Regs '02	8.8	3.1	0.5	n/a
	Building Regs '05	5.8	2.0	0.3	n/a
Transport	VA package	35.9	4.7	2.3	5.1
Total[e]		186.5	8.9	11.9	7.7

Sources: FES, PSI and UK Department for Transport.
[a]The projected savings used in this paper differ from those in the Climate Change Programme 2006 because of slightly different data assumptions.
[b]Compared to projections for final energy demand by sector in 2010 in EP68 (DTI, 2000), average of CL and CH projections.
[c]Compared to baseline projections for CO_2 emissions by sector in 2010 in UK Climate Change Programme (Defra 2000, 2006).
[d](Acronyms (where not already encountered): EEC—Energy Efficiency Commitment; NI-EEL—Northern Ireland Energy Efficiency Levy; CT—Carbon Trust; VA—Voluntary Agreement).
[e]Percentages in relation to total energy and CO_2 savings are similarly compared to average and baseline projections for total UK final energy demand and CO_2 emissions in 2010, respectively, from the same sources.

Table 3
Average annual growth of key macroeconomic variables, base case

	1995–2000	2000–2005	2005–2010
GDP (% pa)	2.84	2.67	2.44
GDP deflator (% pa)	2.14	1.41	2.63
Employment (% pa)	1.3	0.38	0.49

Note: This table shows projections chosen to correspond closely with the actual outcome and represents a solution of the model adopted for the study.
The projections are not intended to be forecasts.
Source: Cambridge Econometrics.
Ref.: MDM95r9 C42Br9.

The growth rates of GDP, price level (GDP deflator) and employment for the base case are shown in Table 3.

4.4. Including the energy saving from the policies in MDM-E3

To implement the scenarios in MDM-E3, the effects of the relevant energy efficiency policy measures are introduced into the model by imposing a reduction in energy use on the estimated aggregate energy demand equations for the sectors affected (using the projected energy savings shown in Table 4). The method for incorporating the effects is illustrated in Fig. 1 for the equation for energy use by the Commerce and Public sector. The values of the equation estimated for *levels* of energy use by the Commerce and Public sector are plotted 1974–2003, labelled as REFERENCE. The projections 2000–2010 show the effects on energy use of the year-by-year permanent increases in energy savings resulting from energy efficiency policies, labelled as BASE, for this sector. As shown in Fig. 1, these savings are introduced gradually over the period and rise to about 5% (the projected saving for this sector) by 2010. Hence, energy use is shown to be about 5% lower by 2010 after the energy efficiency policies have been included. The energy savings for the other sectors are treated similarly. The macroeconomic effects of the energy efficiency policies are found by running the MDM-E3 model, using these energy savings as inputs to the model runs.

5. Results

5.1. Macroeconomic effects of energy efficiency policies

Table 4 shows the macroeconomic effects of the total of the energy efficiency policies as modelled by MDM-E3 (by comparing the base case with energy efficiency policies to the reference case without policies). These effects include the macroeconomic rebound effect, which is distinguished in Section 5.3 below. Overall the policies lead to a saving of about 8% of the energy, which would otherwise have been used by 2010 and a reduction in CO_2 emissions of 10% (or

Table 4
Effects of energy-efficiency policies on key macroeconomic variables

	2000	2005	2010
Difference in levels			
Final energy demand (%)	−0.19	−4.27	−8.1
CO_2 Emissions (%)	−0.18	−4.59	−9.61
GDP (%)	0.05	0.64	1.26
GDP deflator (%)	−0.05	−1.01	−2.4
Employment (%)	0	0.27	0.84
Public sector net borrowing (%GDP)	0	−0.22	−0.6
Difference in average annual growth rate	1995–2000	2000–2005	2005–2010
GDP (pp)	0.01	0.12	0.13
GDP deflator (pp)	−0.01	−0.2	−0.29

Notes: Differences in levels are base case less reference case.
Final energy demand corresponds to Final Consumption, Table 1.1, in DUKES, excl non-energy use.
CO_2 emissions refer to whole-economy UK CO_2 emissions.
Public sector net borrowing is change in government expenditure less government income as % reference case GDP in current prices.
Differences in average annual growth rates are percentage point differences, base case less reference case.
Source: Cambridge Econometrics.
Ref.: MDM95r9 C42BR9 C42RR9.
Note: In this and subsequent tables, a positive figure indicates an increase with respect to the reference case, and a negative figure a reduction with respect to the reference case, e.g. a reduction in final energy demand due to energy efficiency policies is shown as a negative figure.

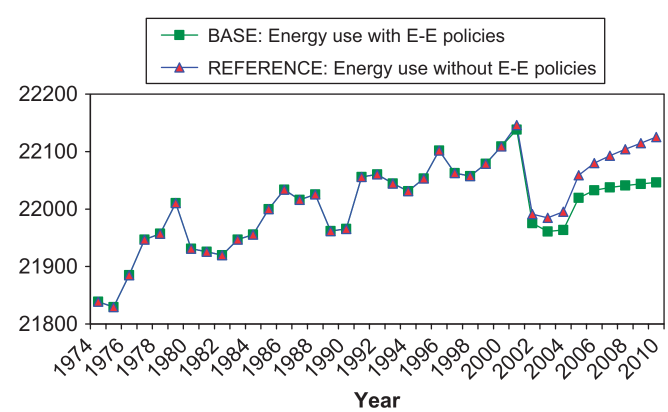

Fig. 1. Explained energy use for commerce, etc.

14 mtC) by 2010. The table also shows the effects on GDP, the general price level (the GDP deflator) and employment for 2000, 2005 and 2010 and GDP growth and price inflation for 2000–2005 and 2005–2010. The energy saving shows up as macroeconomic benefits in two main forms: firstly lower prices and lower inflation, as the production system requires fewer inputs to produce the same output; and secondly higher output and growth, partly the consequence of the lower inflation, as households spend more in response to their higher imputed income when their energy bills are reduced for the same level of energy

services provided. The changes are relatively small: prices are on average about 3% lower by 2010 (corresponding to a 0.3% reduction in the annual growth rate of prices for 2005–2010) and the level of GDP is about 1% higher by 2010 (or a 0.1% increase in the annual growth rate for 2005–2010).

5.2. Impacts of energy efficiency policies on energy demand and CO_2 emissions

Table 5 shows the effect of energy efficiency policies on final energy demand only in energy units (mtoe), grouped by six final-user sectors of the economy, again incorporating macro-economic rebound effects. Overall the reduction is about 14 mtoe, 8% of total energy demand by 2010. The demand falls over the decade as the energy efficiency policies gradually strengthen and their effects accumulate, with the industrial policies, focused on the CCAs, coming early in the period, while the other policies are taking more time to take effect. The table shows the substantial differences between the sectors, with households showing the largest reduction in absolute terms. However the energy-intensive industries show the largest reduction in relative terms, as a percentage of their energy demand, at 15%, compared with 10% for households, 6% for road transport, 5% for commerce and a small increase for air transport (due to the rebound effect, as no energy efficiency policies were modelled for this sector).

Table 5
Effect of energy policies on final energy demand by sector, mtoe

	2002	2004	2006	2008	2010
Energy-intensive industries	−1.68	−1.69	−1.73	−1.76	−1.86
Other industry	−1.27	−1.64	−1.91	−2.18	−2.35
Road transport	−0.74	−1.43	−1.91	−2.38	−2.81
Air transport	0.01	0.04	0.05	0.07	0.09
Commerce, etc.	−0.1	−0.26	−0.55	−0.87	−1.17
Households	−0.48	−1.36	−2.57	−4.15	−5.71
Total	−4.26	−6.34	−8.63	−11.27	−13.82

Notes: Figures are base case less reference case.
Final energy demand corresponds to Final Consumption, Table 1.1, in DUKES, excl non-energy use.
Source: Cambridge Econometrics.
Ref.: MDM95r9 C42BR9 C42RR9.

Fig. 2 shows the effects of energy efficiency policies on total final energy use for the UK economy 2000–2010, showing the net energy saving, after the (exogenously estimated) direct rebound and (calculated) indirect rebound effects are taken into account. The figure shows the scale of these effects and how they accumulate over the period. Fig. 3 shows how the energy savings from the policies are distributed across the main sectors in which they are implemented: business dominates in the early years as the CCAs are mainly effective when they were introduced with the CCL in 2001, with over-achievement of the CCA targets over the period to 2005.

5.2.1. Effects on gross output and prices

The principal measure of production in MDM-E3 is gross output, since this includes industrial demand for products as well as final demand. The largest differences in gross output by 2010 are shown in Fig. 4 as % change from reference, for the four industrial sectors most negatively and most positively affected, with the associated price effects shown alongside. Gross output changes because improved energy efficiency reduces industrial costs and prices and increases industrial investment, so raising price and non-price competitiveness. Exports are higher than otherwise, and imports are lower. At the same time the higher energy efficiency in household use of energy increases real consumer incomes, and leads to a switching of expenditures, depending on price and income elasticities (discussed below). The net effect on output and imports is that they are nearly all slightly higher, excluding energy products.

Three features stand out in the changes shown in Fig. 4. First, the large reductions in gas and electricity outputs dominate the sectoral results (changes of −9.5% for gas and −7.8% for electricity). The large changes represent the accumulated effects of all the policies across the economy. Second, the increases in output are widespread but much

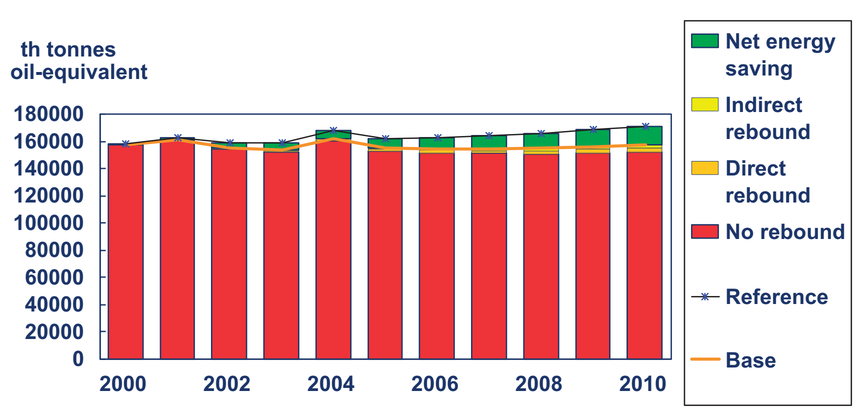

Fig. 2. Effects of energy efficiency policies on UK final energy demand 2000–2010.

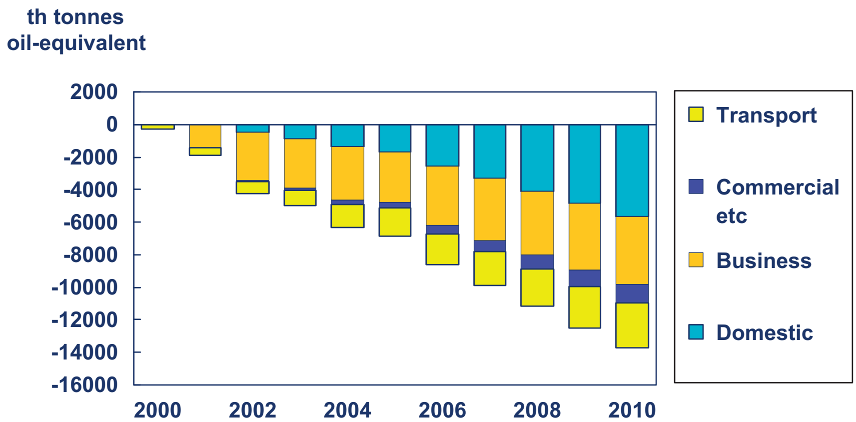

Fig. 3. Disaggregation of net energy saving from energy efficiency policies 2000–2010.

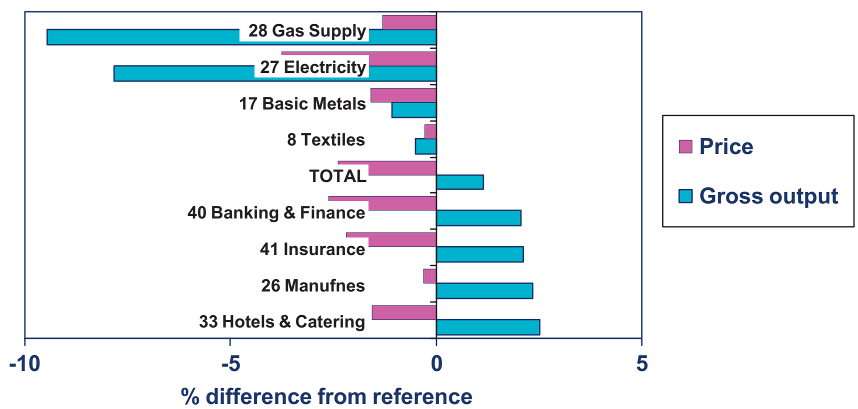

Fig. 4. Largest effects of energy efficiency policies on gross output and prices by sector in 2010. *Note*: Fig. 4 shows the four most negative and the four most positive effects on gross output, with the effects on prices shown alongside.

smaller. The sectors with higher output are mainly services, especially the most income-elastic, with hotels and catering the highest (2.5%), although there are many sectors with output over 2% higher by 2010. Air transport is included in this group, leading to the small rebound effect for air transport fuels. Third, total gross output is 1.1% above reference case by 2010.

5.2.2. *Effects on employment*

Overall an 0.8% (or 271,000) increase in employment is calculated by 2010 as a result of the policies. The extra employment is concentrated in the service industries and construction: Health and social work (higher by 21,000 by 2010), Other business services (22,000), Miscellaneous services (22,000), Education (25,000), Construction (32,000), Hotels and catering (34,000). Nearly all the sectors with the larger increases in employment are geographically dispersed, and any extra pressure on wage inflation from these increases and the corresponding decreases in unemployment is likely to be small.

5.2.3. *Effect on consumers' expenditures*

The effects on consumer spending are comparable, with the reductions of between 8% and 12% spread across the energy sectors. The sectors with higher increases are air travel, and catering, but purchases of vehicles is highest, as a result of a high-income response and extra investment by consumers in more fuel-efficient private cars.

5.2.4. *Impacts on CO_2 emissions*

The above reductions in final energy demand, together with small reductions in own use of energy in the power generation and other fuel sectors, arising from energy efficiency policies, lead to a reduction in CO_2 emissions. Note that, in the MDM-E3 model, CO_2 emissions are allocated at the point of emission, so that reductions in CO_2 emissions from power generation reflects both reductions in final electricity demand and reductions in own use of energy in power generation. Table 6 shows the effects of the energy efficiency policies on CO_2 emissions, grouped into power generation and the six final-user sectors. The contribution from power generation to the

Table 6
Effect of energy efficiency policies on CO_2 emissions by sector, mtC

	2002	2004	2006	2008	2010
Power generation	−1.77	−1.65	−2.65	−3.73	−4.67
Energy-intensive industries	−1.42	−1.36	−1.37	−1.4	−1.48
Other industry	−0.63	−0.79	−0.96	−1.1	−1.17
Road transport	−0.54	−1.04	−1.39	−1.74	−2.05
Air transport	0	0	0.01	0.01	0.01
Commerce, etc.	−0.06	−0.14	−0.28	−0.44	−0.58
Households	−0.24	−0.68	−1.33	−2.17	−3
Total	−4.91	−6.07	−8.59	−11.4	−13.98

Notes: Figures are base case less reference case.
Total CO_2 emissions includes emissions from energy intensive industries' own use of energy, rail transport and water transport.
Source: Cambridge Econometrics.
Ref.: MDM95r9 C42BR9 C42RR9.

overall reduction in CO_2 from the policies is substantial, about one-third of the total 13.9 mtC by 2010.

5.3. Calculation of macro-economic rebound effect

Table 7 shows the magnitude of the macroeconomic rebound effect on energy demand arising from all energy efficiency policies (in the base case), disaggregated by sector of the economy, having assumed the direct rebound effects. The effects are calculated by taking the difference between the energy saving projected by the model and the expected *net* energy saving (after allowing for the direct rebound effect) projected from energy-engineering studies for the policies (as set out in Table 4 above). This difference is then expressed as a percentage of the expected *gross* energy saving from these studies. The macroeconomic results show that the reduction in energy demand in 2010 is around 11% less than expected due to several indirect and economy-wide interactions discussed below, which have been ignored in the energy-engineering studies. Higher macroeconomic rebounds in the energy-intensive industries sector (25%) are offset by lower macroeconomic rebounds in the road transport, commerce and household sectors.

In industry, the targeted reductions in energy and carbon intensities in the energy-intensive industrial sectors (due to the CCAs) lead to a reduction in industrial costs and therefore prices, and consequently more output and net exports, which form largest contribution to indirect rebound effects. The CCA sectors typically have reductions in price and increases in output, whilst the gas and electricity sectors have increases in price and reductions in output.[3]

The reduction in prices are spread across many manufacturing industries, and the increases in their price competitiveness leads to increases in exports and reductions in imports, without much change in final demand, which is largely served by imports at the margin. The extra output leads to higher energy demands, including those from other energy-intensive industries, leading to a much higher than average rebound effect. The increase in liberalised prices of gas and electricity in the industrial markets come about because both the gas and electricity industries have high fixed costs in relation to output (mainly transmission and generating capital, with low labour intensities compared to other industries). When the demand goes down, unit costs rise and these are passed on into prices. There will be a reduction in the utilisation of capacity in the energy industries.

[3]These wider macro-economic effects of the CCAs are discussed in more detail in another paper (Barker et al., 2007).

Table 7
Macroeconomic rebound effect (%), difference between base case and reference case, 2005–2010

	2005	2010
Energy-intensive industries	27	25
Other industry	15	16
Road transport	4	7
Commerce, etc.	0	7
Households	5	7
Total	12	11

Note: Figures are percentage reduction in anticipated energy saving due to macroeconomic effects in MDM-E3 projections.
Source: Cambridge Econometrics.
Ref.: MDM95r9 C42BR9 C42RR9.

The highly disaggregated nature of the MDM-E3 model gives detailed insights into the indirect and economy-wide interactions, which give rise to the macroeconomic rebound effect. Three main potential sources of these overall macroeconomic effects arising from the introduction of energy efficiency policies have been identified:

(1) *Higher imputed incomes for private consumers*. The reduction in energy costs implies an increase in consumer incomes. With the introduction of tighter building regulations and other policies to improve efficiency by the domestic sector, market energy prices are largely unchanged, but gross energy use falls if the volume of energy services remains the same. The higher real incomes must be imputed and allocated to consumers so that they increase their spending, as if they had an increase in actual income.
(2) *Higher investment directly associated with the energy efficiency policies*. Examples are the cost of extra insulation of houses or the extra cost of a fuel-efficient car over another with similar characteristics, but lower efficiency. This extra investment, provided as the costs of the policies to consumers and business associated with the energy efficiency measures, is added to industrial investment for the CCA sectors, to investment in office buildings and dwellings and to the investment in road vehicles by consumers.
(3) *Lowering of energy use and industrial costs*. The lower energy costs for consumers enable them to reallocate

Table 8
Sources of macroeconomic effects of energy efficiency policies: UK 2010

	Higher imputed income	Higher energy efficiency investments	Lower energy use and industrial costs	Total (%)
Final energy	0.1	0.0	−8.1	−8.0
CO_2 emissions	0.2	−0.2	−9.5	−9.6
GDP	0.5	0.5	0.3	+1.3
GDP deflator	−0.8	−0.8	−1.0	−2.4

Note: The table shows contributions to % difference between base case and reference case, from scenarios that decompose the total effects into three components.
Source: Cambridge Econometrics.
Ref.: BRRC9, RCRV9, RVRR9, BRRR9.

spending away from gas and electricity to a wide range of other goods and services, typically with very small energy and carbon content. In industry, the targeted reductions in energy and carbon intensities in the CCA sectors lead to a reduction in industrial costs and therefore prices, and consequently more output and exports.

Table 8 shows the relative contributions of these three sources to the overall change in final energy demand, CO_2 emissions, GDP and price deflation. The table shows that this extra spending due to higher imputed income leads to slightly higher energy use (a rebound effect) and emissions, but even higher GDP and consumers' expenditure in total. This shows that the increased economic activity due to changes in consumer income mostly occurs in less energy-intensive areas, i.e. use of energy and carbon is inelastic to changes in consumer income. Similarly, the extra investment stimulated by energy efficiency policies is itself concentrated on measures, which reduce carbon emissions, whilst increasing economic activity. The lowering of domestic and industrial energy costs is the main source of reduced CO_2 emissions and a major contributor to the reduction of prices.

Table 8 thus shows that nearly all the indirect and economy-wide rebound effects on final energy use (which are contained within the figure of −8.1%) are due to the higher GDP resulting from greater energy efficiency. The lower energy costs for consumers lead them to reallocate spending away from gas, electricity and gasoline/diesel to a wide range of other goods and services, typically with very small UK energy and carbon content, and hence the rebound effect shown in Table 7 is low.

However, it should be noted that a proportion of this reallocated spending will be on imports and non-UK consumption, whose energy and carbon content are not calculated within our model. For example, for households some of the most energy-intensive and income-elastic items of spending are purchases of vehicles, air travel and foreign tourism. For these, the extra increase in energy use needed to provide the goods and services partly or largely comes from abroad through the energy embodied in the imports of vehicles and tourist services. The energy saving from less use of UK-produced gas and electricity is partly offset by more use of oil-based energy, which is consumed abroad and the rebound effect defined for UK consumption is thereby reduced. The implicit energy content of imported vehicles, travel and tourism is likely to be as high if not higher than that of the domestic production. Therefore, the total rebound effect, including the energy content of imports will be larger than the UK effect. Since the extra imports are approximately 40% of the extra domestic output, the increase will be significant, but it is not possible to be more precise without further research.

The low rebound effects we find are consistent with the long-run parameters included in the aggregate energy equations for the response of energy demand to economic activity. All these activity elasticities are below one in the range 0.75 (basic metals) to 0.1 (chemicals), with road transport 0.7 and households 0.2. Energy demand is therefore partly disengaged from activity in the long run. The low responses are interpreted as the outcome of several features in energy use. Firstly, the activities within each broad sector are typically shifting over time towards more service-based and less material-energy-based activities as incomes rise and quality improves; energy demand will grow more slowly than activities as a result. Secondly, technological progress is taking the diffused form of more control in production and distribution and more precise use of energy in the form of electricity rather than fossil fuels directly; aggregate energy grows less, but the share of electricity rises. Thirdly, much of energy use for heating and cooling of buildings (commercial and household use of energy) is largely an overhead cost, once comfort levels are reached; in consequence, energy use will be associated more with employment and numbers of households, rather than with output and incomes. Employment and numbers of households grow much less than GDP and incomes.

5.4. Calculation of the 'total' rebound effect

The macroeconomic rebound effect calculated here using the MDM-E3 model includes both the indirect and economy-wide rebound effects, as explained above. Though the MDM-E3 model disaggregates economic activity into 50 industrial sectors and 13 types of fuel user,

Table 9
Total rebound effect (%), difference between base case and reference case, 2005–2010

	2005	2010
Energy-intensive industries	27	25
Other industry	15	16
Road transport	29	32
Commerce etc.	0	7
Households	33	30
Total	26	26

Note: Figures are total rebound effect, i.e. (assumed) direct rebound plus (projected) indirect rebound.
Source: Cambridge Econometrics.
Ref.: MDM95r9 C42BR9 C42RR9.

this is not sufficient to be able to use the model to calculate direct rebound effects, as these are highly specific to different types of energy service end-use. Hence, the magnitudes of these direct rebound effects have been assumed in the model and taken from external assessments. However, calculations of the macroeconomic rebound effect using other approaches, such as computable general equilibrium modelling, usually do not distinguish between these types of rebound effects, and hence include direct rebound effects in their estimation of macroeconomic rebound effects. So, in Table 9, we give our estimate of the 'total' rebound effect by economic sector, given by adding our assumed values for the direct rebound effects (25% for transport and 28% in 2005 and 23% in 2010 for households) to our calculated value of the macroeconomic rebound effect.

6. Conclusions

The findings of this study support the argument that energy efficiency improvements for both consumers and producers stimulated by policy incentives do not give rise to very large macroeconomic rebound effects, i.e. only a relatively small proportion of the expected energy savings are lost due to indirect and economy-wide effects. This result arises partly because the focus of the study has been on actual policies in place for final energy users, which are focused on addressing market failures/barriers. Indeed, the results suggest that there may be positive macroeconomic effects in economic terms, with small increases in GDP and employment, and small reductions in prices, alongside significant reductions in final energy demand and CO_2 emissions, resulting from energy efficiency policies and programmes (see Table 5).

We find that the macroeconomic rebound effect arising from announced UK energy efficiency policies and programmes for final energy users over the period 2000–2010 is around 11% by 2010, averaged across sectors of the economy. When this is added to the (assumed) direct rebound effect of around 15%, this gives a total rebound effect of around 26% arising from these policies and programmes. The decomposition of these effects is interesting. The largest direct rebound effects are for the road transport and household sectors, whereas the largest indirect rebound effects are for the energy-intensive and other industry sectors, with small direct and indirect rebound effects for the commerce sector.

The macroeconomic rebound effects arise from the reduction in energy costs for consumers and producers (particularly for energy-intensive industries). The lower energy costs for consumers lead them to substitute away from gas and electricity to a wide range of other goods and services, typically with relatively small energy and carbon content, hence the rebound effect is low. In industry, the targeted reductions in energy and carbon intensities in the CCA sectors lead to a reduction in their industrial costs and therefore prices, and consequently more output and exports. These extra outputs are more energy intensive than average, so there is a higher rebound effect.

Further model runs, undertaken for a sensitivity analysis (see Cambridge Centre for Climate Change Mitigation Research (4CMR) et al., 2006) suggest that a significant increase in the strength of energy efficiency policies (e.g. a doubling) would lead to further energy and CO_2 savings, with the size of the total rebound effect being slightly reduced. The 'Khazzoom–Brookes postulate,' which states that energy savings from all energy efficiency measures are likely to be offset by associated increases in demand, is based on an extrapolation of simplified theoretical models of the whole economy. Our more detailed macroeconomic model is able to take into account the size and focus of actual energy efficiency policies, relative to the UK national economy. Although we find appreciable macroeconomic rebound effects of the order of 20–30% for energy-intensive sectors, those for the other sectors are much smaller, from 5% to 10%, because they are much less energy intensive.

Hence, the results of this study contradict the Khazzoom–Brookes postulate and support the argument that improvements in energy efficiency by producers and consumers, stimulated by government policy measures, will lead to significant reductions in energy demand and hence in greenhouse gas emissions.

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