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Determining the impact of regulatory policy on UK gas use using Bayesian analysis on publicly available data

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HIGHLIGHTS

- We investigate the impact of a UK policy to require new boilers to be high efficiency.
- Theoretically informed models are developed and applied to national data.
- Bayesian analysis is used to find best fit parameters and compare model performance.
- The policy is prescriptive and simple to enforce; it improves stock boiler efficiency.
- Significant energy and carbon savings may be associated with this policy.

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ABSTRACT

This paper presents a novel method to analyse policy performance, using the example of legislation in the UK to require domestic boilers fitted since 1 April 2005 to be condensing. A technological uptake model based on the logistic equation is combined with four physical and economic models; Bayesian techniques are used for data analysis. Projections of energy savings are presented and the impact of different policy implementation dates investigated.

Boiler efficiency is estimated to improve by a factor of 1.25 ± 0.15 on replacing a conventional with a condensing boiler. Estimated savings of the policy are $176,000^{+86,000}_{-127,000}$ GW h (or 32^{+16}_{-23} MTons of CO_{2e}) between introduction in 2005 and 2013. Total estimated savings by 2050 of introducing the legislation in 2005 are $2,000,000^{+1,000,000}_{-1,500,000}$ GW h (or 368^{+184}_{-276} MTons of CO_{2e}), approximately 5.6 times the average annual domestic UK emissions from domestic gas use of approximately 66 ± 5 MTons of CO_{2e}.

Nomenclature

Symbol	Units	Meaning
n	day	Model variable: day index number counting from 1st January 1990.
$N_D{}^n$	Millions	Predicted number of dwellings in England on day n
$N_B{}^n$	Millions	Predicted number of gas boilers in England on day n
$N_C{}^n$	Millions	Predicted number of condensing gas boilers in England on day n
$N_{NC}{}^n$	Millions	Predicted number of new condensing gas boilers in England on day n after the switch date
$N_{RC}{}^n$	Millions	Predicted number of replacement condensing gas boilers in England on day n after the switch date
$N_D{}^0$	Millions	Parameter: number of dwellings in England at the start of the analysis period 1st January 1990, when $n=0$
$N_B{}^0$	Millions	Parameter: number of dwellings in England with a boiler at the start of the analysis period 1st January 1990, when $n=0$
$N_C{}^0$	Millions	Parameter: number of dwellings in England with a condensing boiler at the start of the analysis period 1st January 1990, when $n=0$
r_D	Millions per day	Parameter: intrinsic linear rate of dwelling creation
r_B	Millions per day	Parameter: intrinsic rate of growth

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		of boilers in the stock
r_{C1}	Millions per day	Parameter: intrinsic rate of growth of condensing boilers in the stock before 1st April 2005
r_{C2}	Millions per day	Parameter: intrinsic rate of growth of condensing boilers in the stock after 1st April 2005
γ	Fraction	Parameter: fractional change in efficiency upon replacement of a conventional with a condensing boiler
F^{EUK}	Ratio	Set parameter: ratio of dwellings in UK to England
η_{NC}	Fraction	Model variable: fractional efficiency of non-condensing boilers
η_{C}	Fraction	Model variable: fractional efficiency of condensing boilers
η	Fraction	Model variable: fractional efficiency of the stock
E	GW h/Quarter	Predicted quarterly gas consumption in the UK
T_{ext}	°C	Data: measured quarterly average external temperature
T_{BAL}	°C	Parameter/model variable: balance temperature
T_k	°C	Parameter: internal temperature constant
P	Index	Data: measured quarterly average gas consumer price index
S	MW h/quarter/dwelling	Model variable: gas needed/demanded for space heating
E	MW h/quarter	Model variable: UK quarterly gas demand
W	MW h/quarter/dwelling	Model variable: gas needed/demanded for water heating
W_k	MW h/quarter/dwelling	Parameter: water heating constant
G_{TP}	°C/price	Parameter: change in internal temperature due to price changes
G_P	MW h/quarter/dwelling/price	Parameter: change in gas use for space and water heating due to price changes
G_{WP}	MW h/quarter/dwelling/price	Parameter: change in gas use for water heating due to price changes
G_{WT}	MW h/quarter/dwelling/°C	Parameter: change in gas use for water heating due to external temperature changes
G_{SP}	MW h/quarter/dwelling/price	Parameter: change in gas use for space heating due to price changes
G_{ST}	MW h/quarter/dwelling/°C	Parameter: change in gas use for space heating due to changes in the external-internal temperature difference
A, B		Parameters: dummy parameters
$Prob$		Probability distribution
H		Hypothesis
D		Data: either gas consumption or number of houses
$\mathcal{E}$		Long-run price elasticity of domestic gas use
Ω		Parameter set

1. Introduction

The potential consequences of climate change have induced many countries to commit to reduce their carbon emissions (IPCC, 2007; UNFCCC, 2012). For example, the UK government has committed to an 80% reduction in its carbon account from 1990 levels by 2050 (Climate Change Act, 2008). A raft of policies, spanning energy supply and demand in the industrial, transport, domestic and commercial sectors, aims to bring about this transformation (DECC, 2011); however, assessing the efficacy of policies remains challenging due to the complex interplay of economic, social and physical factors (Foxon, 2011). The full impact of a policy may take many years to become apparent.

Domestic water and space heating were responsible for approximately 26% of UK energy consumption in 2012, primarily supplied by the local combustion of natural gas, which is thought to account for approximately 81% of domestic consumption for heat (DECC, 2014c). A range of mitigation policies have been proposed to decrease carbon emissions associated with domestic heating (DECC, 2011). Building regulations are projected to deliver 44% of residential sector energy savings in the fourth Carbon Budget (DECC, 2012). This paper presents an analysis to determine the efficacy of energy consumption policies, using the example of legislation to mandate the installation of high efficiency boilers for new and replacement systems via the Building Regulations (ODPM, 2005).

1.1. Condensing boiler legislation

On 1 April 2005 an amendment to the Building Regulations came into force in England and Wales requiring that, apart from exceptional circumstances, all domestic gas boilers for new and replacement systems should be rated SEDBUK (Seasonal Efficiency of Domestic Boilers in the UK) A or B (ODPM, 2005). The minimum required efficiency (defined in terms of gross calorific value of natural gas) is 86%, necessitating the use of a condensing boiler (ODPM, 2005). The proportion of condensing boilers in the domestic stock has subsequently risen from ~5.7% of all boilers in 2004 to 42.8% in 2011 (DECC, 2014c). In this paper we treat the 2005 regulations as triggering a step change in condensing boiler uptake and therefore stock efficiency; however, significant improvements in boiler efficiency will have occurred prior to, and after, this date due to a range of factors including legislation, maturing technology and market competition. In this analysis all non-condensing boilers have one fixed efficiency regardless of age, condensing boilers have a different fixed efficiency, changes in the fixed efficiencies for each boiler type are incorporated into uncertainty estimates.

The introduction of condensing boilers, of higher efficiency than traditional boilers, is expected to decrease the carbon intensity of heating. However, reductions in gas usage may be partially offset by consumer comfort taking and rebound (Sorrell, 2007; Sorrell et al., 2009). Additionally, upgrading a dwelling's boiler may result in a physical rebound whereby the system is capable of achieving thermostat set-point over a wider range of external conditions, or simply achieve set-point faster than previously, thus raising the mean internal temperature and increasing the heat losses from the dwelling (Deurinck et al., 2011). Further, the in situ performance of installed boilers may be below their designed efficiency for a range of complex reasons, including return water temperatures being too high for condensing operation; a setting that may be adjusted at installation, servicing or during operation by professionals and occupiers (Orr et al., 2009). Field trials of condensing boilers in the UK reported efficiencies