Applied Geography 52 (2014) 1–13

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

Residential solid fuel use: Modelling the impacts and policy implications of natural resource access, temperature, income, gas infrastructure and government regulation

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Keywords:
Solid fuel
Natural resource
Policy
Fuel poverty
Spatial econometrics
GIS

A B S T R A C T

Reducing solid fuel use for home heating can reduce both carbon emissions and air pollution within residential areas and thereby provide for improved environmental and health outcomes. The general models used to identify the determinants of solid fuel use often focus upon socioeconomic factors. Utilising an extended spatial econometric approach our results show proximity to a solid fuel resource as the most significant factor. Other spatially evaluated attributes, such as temperature, legislated solid-fuel sale restrictions and gas network coverage, are also found to have significant impacts on solid fuel use choices. Clear spatial dependence patterns are found for the effects of these attributes, with further evidence of large spill-over effects for neighbouring areas in the case of proximity to either a peat bog or an area subject to a ban on the sale of smoky coal. The research engages a blend of GIS and spatial econometric analysis to generate maps for both a fuel poverty risk and a resistance to fuel change index. These outcomes can serve to inform the design and deployment of effective and equitable solid-fuel and environmental policy interventions. Suggested policy interventions include conservation of peat bogs, expansion of smoky coal ban areas and the development of gas network coverage to specific areas. In addition to the policy support outcomes, the paper offers technical and methodological innovations in relation to combining spatial attributes with econometric models, handling large spatial matrices, understanding direct and indirect effects, and visibly presenting estimated values with spatial dependence.
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Introduction

Solid fuel burning in the residential sector is a source of a variety of emissions including CO_2 and particulate matter, with levels dependent upon the fuel types, combustion processes, and, of course, the scale of such solid fuel burning activities. The associated emissions not only contribute to global warming (Clinch & Healy, 2000a), but are also linked to severe adverse health outcomes including lower respiratory infections (LRI) and chronic obstructive pulmonary disease (COPD) for those exposed, and this has tangible implications for quality of life and health care costs (Clancy, Goodman, Sinclair, & Dockery, 2002; Mehta & Shahpar, 2004; WHO, 2013). Direct policies that regulate solid fuel sale or use can deliver emission reductions from the sector, and similarly other market-based instruments may be used to support changes in solid fuel use patterns. However, in seeking to change behaviour with regard to solid fuel use in the residential sector, policy makers should consider the factors which influence residential choices in this regard. These factors may include cultural preferences, socio-economic considerations, local access to the fuels, and surrounding natural, infrastructural and environmental factors. In this paper we draw on a variety of data sets and spatial econometric methodologies to inform the development of policy interventions using Ireland as a case study. To begin we discuss the proportion of various types of fuels used in Ireland and their spatial distribution.

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http://dx.doi.org/10.1016/j.apgeog.2014.04.007
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Fuel prices and fuel use proportions in the domestic sector

According to the Small Area Population Statistics (SAPS) 2011,[1] for space heating purposes, the most popular fuel used in Ireland is home heating oil, and the second is natural gas. Solid fuel, which includes peat, coal and wood in the statistics, is used in 11.2% of all households. Compared with other countries, Ireland has a low proportion of electricity use in home heating. As Howden-Chapman et al. (2012) point out, Ireland lay 16th of 30 OECD countries in 2008 in this regard. The exact proportions are shown in Table 1. The corresponding costs of different types of fuels are also listed. "Efficiency" in the table reports the best estimated efficiency that a type of fuel can achieve. Delivered energy costs are values in cent per kWh and efficiency-adjusted costs assume the best possible efficiency for combustion, but modify the cost in cent per kWh to take account of the energy lost through the remaining inefficiency gap, thus providing a conservative lower-bound estimate for the actual efficiency-adjusted cost.

One can see that the share of the fuels used in the domestic sector is inconsistent with the costs in terms of ranking. For example, oil has a relatively high cost, however, it also has the highest share of use for home heating at 44.45%. The reason we highlight both delivered-energy costs and efficiency-adjusted costs here is that, for fuel poor households, focussing on the delivered costs may be a factor in making a less efficient long-term choice. Solid fuels have the lowest delivered energy costs and relatively low adjusted costs, though it is important to remember that this is based on an assumption of the best available efficiency being achieved for their combustion. When we factor in air quality, health and convenience, a qualitative comparison suggests there are far cleaner and more convenient options available for the 10% of the population or so that still rely principally on solid fuel combustion to heat their homes. Therefore, we proceed to assess the factors behind these solid-fuel use choices and will discuss the related issues in terms of energy consumption, environmental implications, fuel poverty and national policy.

Spatial distribution of fuel use

Based on the SAPS data, the ratio of households that use solid fuel and oil are shown in Fig. 1 a and b, respectively. From Fig. 1a, we can see that solid fuel is mainly used in the midlands and west coast of Ireland. Those areas within the red polygons (in the web version) are smoky coal ban areas where the sale of bituminous coal is prohibited. The colours within these areas are generally a light shade or white, indicating a successful outcome of the policy in terms of transition away from solid fuels. Oil use counter-balances the solid fuel use pattern. The light areas in the oil use map are the dark areas in the solid fuel use map and vice versa. This suggests that solid fuel and oil are two strong substitutes in many parts of Ireland.

Up to now, we have neglected another major fuel, natural gas, which serves 34.39% of the market. Fig. 2 shows that the use of gas is mainly focused within large cities or towns that exist in the vicinity of the main gas pipeline network. We can see that nearly all places that have a gas-use ratio greater than 14.7% are in the smoky ban areas. These smoky ban areas mainly cover towns with a population greater than 15,000 or that are near the Greater Dublin Area. This alignment to the gas network may be an important factor in the success of this smoky coal ban policy intervention.

Table 1
Proportion of domestic fuels and comparison of costs.

	Peat	Coal	Wood	Oil	LPG	Gas	Electricity
Proportion	4.91%	4.95%	1.34%	44.45%	0.65%	34.39%	8.78%
Delivered Energy cost	5.82	4.90	6.58	10.11	18.27	6.88	26.10
Efficiency	60%	60%	90%	90%	90%	90%	100%
Efficiency-Adjusted cost	9.70	8.17	7.31	11.23	20.30	7.64	26.10

Notes: Proportion is the proportion in household numbers. The non-stated part of the statistics is eliminated from both the denominator and numerator of the proportion calculation. Energy costs are delivered energy costs in cent/kWh and it is the average the costs of a specific type of fuel listed in the SEAI's document.
Source: Proportion from Census data 2011 and cost data from SEAI, Domestic Fuel Costs Comparison, 2013. http://www.seai.ie/Publications/Statistics_Publications/Fuel_Cost_Comparison.

Our paper initially seeks to determine whether natural resources and other spatial attributes such as temperature, proximity to gas network coverage and smoky coal ban areas can explain solid-fuel use choices. The analysis is grounded in GIS spatial processing and spatial econometrics. The next section reviews the literature. Section Factors that affect solid fuel use discusses the factors that affect solid fuel use and presents their spatial distribution. Section Methodology outlines the methodology. Section Results from spatial econometric analysis discusses the results from the spatial regression. Section Fuel poverty risk areas and resistance to change index presents policy outcomes of the paper including a fuel poverty risk map and a resistance to change index map. The last section concludes with a discussion of policy interventions that are designed to reduce solid fuel use.

Literature review

In the existing literature, the common determinants of fuel choice considered are socio-economic factors and features of dwellings. For example, Rehfuess, Briggs, Joffe, and Best (2010) found that in Africa higher education levels and greater income or wealth can reduce the use of solid fuel. Sardianou (2008) tried several econometric models and his results suggest that age, family size, income, dwelling size and rate of occupancy can explain the difference in space heating consumption of oil in Greece, with the last two factors positively correlated to the amount of oil used. Clinch and Healy (2000c) imply that in Ireland, there is a positive relationship between low income households, apartments, terraced or old houses and the use of open fires for space heating. With a questionnaire survey in Germany, Michelsen and Madlener (2013) argued that the households' motivation for adopting more efficient or cleaner fuels has six dimensions which include rational factors and emotional factors. These six dimensions are costs, government grants, general attitude towards home heating, reactions to environmental and energy supply security considerations, comfort considerations and influence of peers. Clinch and Healy (2000b) pointed out that information gaps, significant capital expense (switching to a new heating system), a lack of clarity around property rights for rental accommodation, and a deviation between private and social benefits of improvements can also explain the lack of take-up of more energy-efficient solutions.

Although socio-economic factors are important determinants, as solid fuels are usually traditional fuels and cannot be transmitted to households through pipes or wires, we may also be interested in whether solid fuel use is connected to local resources. Historically, traditional fuels did not have modern vehicles or mechanism to distribute them, therefore, local people built up a degree of consumer inertia (Dubé, Hitsch, & Rossi, 2010) with respect to using the local

[1] Small Area Population Statistics 2011 is a dataset from CSO Ireland: http://www.cso.ie/en/census/census2011smallareapopulationstatisticssaps/. Small areas are smallest census areas in Ireland and thus give us a detailed distribution of fuel use and household features. There are 18488 small areas in all and a typical small area has 80–150 households.

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