UNIVERSITY OF CAMBRIDGE | Energy Policy Research Group

Applying Bayesian Model Averaging to Characterise Urban Residential Stock Turnover Dynamics

EPRG Working Paper 1933

Cambridge Working Paper in Economics 1986

Wei Zhou, Eoghan O'Neill, Alice Moncaster, David M Reiner and Peter Guthrie

China is the world's largest building energy consumer. In 2017, total energy consumption in Chinese buildings was estimated at 963 million tonnes of coal equivalent (28.2 EJ). Of this total, urban residential buildings accounted for more than one third. Whilst the size of the urban residential stock is critical to the evaluation of stock-level energy consumption, official statistics only exist up to 2006 and so the trajectory of the stock from 2007 onwards is unknown. To fill this critical gap requires estimating how the urban residential stock has been developing. The stock evolution and expansion are characterised by a turnover process driven by the dynamic interplay between new construction, meeting incremental demand growth as a result of economic growth and rising living standards, existing buildings remaining in use but undergoing an ageing process, and old buildings, which are eventually demolished. As Chinese urban buildings are generally short-lived due to various factors, building lifetime is one of the key determining factors underlying the dynamics of stock turnover. The short lifetime suggests a high turnover rate, the complexity and uncertainty of which have to be understood when estimating total stock and associated energy and carbon impacts. However, no official statistics on Chinese building lifetime exist and empirical data is extremely limited.

There are three main methodological concerns associated with most previous models estimating Chinese building stock: (i) normal distribution representing building lifetime distribution with arbitrary choices of mean and standard deviation parameters; (ii) ambiguity associated with existing building stock size and age profile in the initial year of modelling; and (iii) use of per capita floor area data as proxy leading to inflated estimates. Whilst some recent models partially addressed these issues by calibrating building lifetime distribution parameters using statistics on floor area, fundamentally they took a frequentist approach and produced single point estimates of distribution parameters leading to a single profile of building lifetime without characterisation of uncertainty. In this context, model parameters are treated as being fixed. And the calibration is conditional upon the model structure as given, thereby neglecting the model uncertainty.

By contrast, a Bayesian approach, adopted in our study, treats parameters as random variables and derives posterior distributions of parameters by taking account of both prior

knowledge about parameter values and the likelihood of observing empirical data given certain parameter values. For a given model, this presents a full picture of the likely parameter space, thus enabling a good understanding of the global shape of the distribution. Such a distribution allows parameter uncertainties to be propagated through to emergent behaviours of model outputs. Moreover, a Bayesian approach allows model uncertainty to be estimated. Through Bayesian Model Averaging (BMA), predictions made by individual models are combined in proportion to posterior model probabilities.

From a policy-making perspective, a probabilistic model offers the ability to generate probability distributions over outcomes of policy scenarios. This is important in the context of analysing the decarbonisation of the generally short-lived Chinese buildings, where there is likely to be a strategic trade-off between operational and embodied energy. Taking a Bayesian approach, a probabilistic model incorporating building stock turnover, energy and carbon will enable future research into the probability that one policy, e.g., extending building lifetime to avoid embodied energy, would yield a more favourable outcome for stock-level decarbonisation as compared to another policy, e.g. accelerating stringency of new building design standards. Improving our understanding of these trade-offs is the overarching objective that motivates this study as an integral part of future research involving a fully-fledged building energy model.

Our study applies BMA to develop a probabilistic dynamic model to predict Chinese urban residential stock for the recent historical period of 2006 to 2017. We develop a probabilistic dynamic model characterising the building aging and demolition process and overall stock turnover, then operationalises the model by separately using various candidate parametric survival models (Weibull, Lognormal, Loglogistic, Gamma, Gumbel) as an integral part of the overall model. Finally, we apply BMA to create a model ensemble to combine predictions of the stock evolution pathway made by each candidate survival model based on their respective posterior model probabilities.

In so doing, we provide a first attempt to take a full Bayesian approach to investigate model and parameter uncertainties that were not adequately taken account of by limited existing models targeting Chinese building stock, which is a strategically important but under-researched area. The modelling approach and the results can serve as a baseline for further studies on forecasting building stock development trajectory and analysing energy and carbon impacts, with particular regard to modelling and analysing policy scenarios to investigate the trade-offs across embodied-versus-operational energy and carbon emissions facing Chinese residential buildings.

Contact	wz282@cam.ac.uk
Publication	September 2019
Financial Support	Cambridge Trust, EPRG