Macro-prudential Policy in an Agent-Based Model of the UK Housing Market

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* The views expressed in this presentation are those of the author(s), and not necessarily those of the Bank of England or its committees.
Overview

1. Agent-based models (ABMs)

2. An ABM of the UK housing market

3. Policy experiments

4. Conclusion
Agent-Based Models

• simulate the behaviors and interactions of individual ‘agents’

• generate real-world complexity

• used across a wide range of disciplines
Emergent Behaviour in an ABM: Conway’s Game of Life

Rules:
1. Any live cell with fewer than two live neighbours dies.
2. Any live cell with two or three live neighbours lives on to the next generation.
3. Any live cell with more than three live neighbours dies.
4. Any dead cell with exactly three live neighbours becomes a live cell.

Resulting behaviour (Gosper glider gun):

Initial pattern:

**Strengths**

- Heterogeneity
- Emergent behaviour
- Complex systems, non-linearity and multiple equilibria
- Stylised facts

**Weaknesses**

- Arbitrary behavioural rules
- Calibration challenges
- Difficulties in interpretation
- The Lucas critique
- Requirement of advanced programming skills
A Model of the UK Housing Market: Why ABM?

- enables the modelling of different actors in the housing market:
  - renters
  - first-time buyers
  - home-owners
  - investor households
- allows for non-linear dynamics, such as housing booms and busts
- permits an evaluation of the impact of policies which target a certain segment of the market
Iacoviello (2005): DSGE model with housing sector


Gilbert et al. (2009): Interaction of buyers, realtors and sellers in a spatial ABM

Delli Gatti et al. (2011): Macroeconomic dynamics in the markets for goods, labour and loanable funds

Geanakoplos et al. (2012): ABM of the housing market of Washington, DC, to demonstrate relationship between leverage and housing bubbles

Axtell et al. (2014): An agent-based model of the housing market bubble in metropolitan Washington DC

Erlingsson et al. (2014): Housing market bubbles and business cycles in an agent-based credit economy

Kouwenberg and Zwinkels (2015): Endogenous price bubbles in a multi-agent system of the housing market

Gross and Población (2017): Assessing the efficacy of borrower-based macroprudential policy using an integrated micro-macro model for European households
The Housing Model: Agents

Households

A Bank: Mortgage Lender

A Central Bank

Heterogeneous in

- age
- income
- wealth
Households

Each period (month):

• Some households are born, some die and others age

• Households
  – receive income
  – spend on non-housing consumption
  – make housing choices (rent, buy or sell)
  – pay housing costs
  – save
Housing choices are endogenous, resulting in different “types” of agents:
- Renters decide whether to attempt to buy a house when their rental contract ends.
- Owner-occupiers decide whether to sell their house and buy a new one, or become a renter.
- Investor households decide whether to sell their rental properties and/or buy new ones.
Housing Choices

- Housing choices are endogenous, resulting in different “types” of agents:
  - Renters decide whether to attempt to buy a house when their rental contract ends.
  - Owner-occupiers decide whether to sell their house and buy a new one, or become a renter.
  - Investor households decide whether to sell their rental properties and/or buy new ones.

*The decision of renting vs buying* is based on the relative cost of renting against the cost of mortgage payments and expected capital appreciation.

*The decision to buy or sell a rental property* is based on expected rental yield and expected capital gain.
Housing Choices

– If buying, they choose a desired expenditure and leverage.
– If selling, they decide the price.
– If owning a vacant rental unit, they decide on whether to rent it out.
– If renting, they decide on the amount of rent.
• Fixed housing stock

• But differs in ‘quality’, which is a proxy for size, location, condition etc.
The Bank

- a single bank representing the mortgage lending sector in the aggregate
- approves mortgages as long as they conform to
  - affordability test
  - loan-to-value (LTV) limit
  - loan-to-income (LTI) limit
  - interest coverage ratio (ICR) limit
- subject to meeting those criteria, all demand is met in any month
The Central Bank

- sets LTV, LTI, ICR policies and affordability tests. Policies can be of three types:
  
  - hard limits, e.g. a hard LTV limit of 90 percent;
  
  - soft limits, e.g. an LTI cap allowing a certain percentage above the limit;
  
  - state-contingent policies, e.g. an LTV limit if credit growth is above a certain threshold.
Market Clearing

• Sales market:
  – Owner-occupiers are matched to the best quality house they can afford.
  – BTL investors are matched to the best yield house they can afford.
  – Where a given offered house is matched with more than one bidder, the price is ‘bid-up’ and offered at random to one of the bids that can still afford to buy. The failed bids then get to bid again.

• Rental market:
  – Renters are matched to the best quality house they can afford.
The Housing Model:

- Sales Market
- Mortgage Market
- Rental Market
The Housing Model:

- Rental Market
- Mortgage Market
- Sales Market

Investors ➔

Renters ➔
The Housing Model:

Sales Market

Investors

Owner-occupiers
- FTB
- Home-movers

Mortgage Market

Rental Market

Renters
The Housing Model:

- **Sales Market**
  - Investors
    - Renters
      - Rental Market
    - Home-movers
      - Mortgage Market
        - Owner-occupiers
          - FTB
          - Home-movers
The Housing Model:

- **Sales Market**
  - **Investors**
  - **Renters**

- **Rental Market**

- **Mortgage Market**
  - **Owner-occupiers**
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The Housing Model:

- **Sales Market**
  - Investors
  - Renters

- **Rental Market**

- **Mortgage Market**
  - Owner-occupiers
    - FTB
    - Home-movers
  - Caps on LTI, LTV and ICR ratios, and affordability tests
The Housing Model: FPC`s housing indicators

1. House price growth
2. House price to income ratio
3. OO-LTV and LTI ratios
4. BTL LTV ratio
5. Debt to income ratio
6. Advances to FTB, HM, BTL
7. Credit growth
8. Spread
9. Rental yield

Caps on LTI, LTV and ICR ratios, and affordability tests
The model is calibrated against a large set of micro data, mostly from household surveys and housing market data sources.

The calibration of the model proceeds in two steps:

- A **micro-calibration** that fine-tunes households’ individual characteristics and behaviour;

- A **macro-calibration** that ensures consistency with economic aggregates.
Data Sources
Data Sources

- Wealth and Asset Survey
- Living Costs and Food Survey
- English Housing Survey
Data Sources

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Mortgage Market
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- Wealth and Asset Survey
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Rental Market
Data Sources

- Wealth and Asset Survey
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Mortgage Market

Rental Market

Sales Market
## Micro Calibration

<table>
<thead>
<tr>
<th>Data source</th>
<th>Data/variables used</th>
<th>Calibration of</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Housing market data</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FCA Product Sales Data (PSD)</td>
<td>Loan amount; property value; income; interest rate; type of mortgage holder (e.g. first-time buyer)</td>
<td>LTV; LTI; mortgage interest rate; joint distributions of different variables</td>
</tr>
<tr>
<td>Land Registry Council of Mortgage Lenders (CML)</td>
<td>Sales price of properties; Housing transactions; mortgage advances; interest rates</td>
<td>Distribution of property prices; Housing transactions; mortgage advances of first-time buyers, home movers, buy-to-let investors; distribution of interest cover ratios; Price reduction if property unsold in previous period; distribution of rental prices; distribution of rental yields</td>
</tr>
<tr>
<td>Zoopla</td>
<td>Property sales prices; rents</td>
<td></td>
</tr>
<tr>
<td><strong>Household surveys</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>English Housing Survey (EHS)</td>
<td>Previous tenure; length of residence by tenure</td>
<td>'Birth rate' of households; distribution of length of tenancies; share of cash buyers</td>
</tr>
<tr>
<td>Living Cost and Food Survey (LCFS)</td>
<td>Household income by age of HRP</td>
<td>Income distribution of households by age</td>
</tr>
<tr>
<td>NMG Household Survey (NMG)</td>
<td>Source of housing finance; property ownership</td>
<td>Share of cash buyers vs. mortgage holders; share of BTL investors in population</td>
</tr>
<tr>
<td>Private Landlord Survey (PLS)</td>
<td>Number of properties in portfolio; vacancies; length of residency; rent if re-let</td>
<td>Distribution of portfolio size, landlord weighted and dwelling weighted; share of vacant properties on market; distribution of length of tenancies; changes in rents between tenancies</td>
</tr>
<tr>
<td>Wealth and Asset Survey (WAS)</td>
<td>Household financial wealth; household savings; number of rental properties</td>
<td>Household consumption; aggregate distribution of savings; number of BTL investors</td>
</tr>
<tr>
<td>Survey of Residential Landlords (ARLA)</td>
<td>Residential properties in portfolio; length of lease</td>
<td>Number of rental properties per BTL investor; length of a rental agreement</td>
</tr>
</tbody>
</table>
# Model Validation: FPC`s Housing Core Indicators

<table>
<thead>
<tr>
<th>Core Indicator</th>
<th>FPC’s Policy Statement on housing tools</th>
<th>Housing ABM simulations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum since 1987</td>
<td>Average 1987-2006</td>
</tr>
<tr>
<td>OO mortgage LTV ratio (mean above the median)</td>
<td>81.6%</td>
<td>90.6%</td>
</tr>
<tr>
<td>OO mortgage LTV ratio (mean above the median)</td>
<td>3.6</td>
<td>3.8</td>
</tr>
<tr>
<td>BTL LTV ratio (mean)</td>
<td>70.9%</td>
<td>n.a.</td>
</tr>
<tr>
<td>Household credit growth</td>
<td>-0.1%</td>
<td>10.3%</td>
</tr>
<tr>
<td>OO debt to income ratio</td>
<td>72.8%</td>
<td>86.1%</td>
</tr>
<tr>
<td>Mortgage approvals</td>
<td>26,658</td>
<td>97,940</td>
</tr>
<tr>
<td>Advances to homemovers</td>
<td>14,300</td>
<td>48,985</td>
</tr>
<tr>
<td>Advances to FTB</td>
<td>8,500</td>
<td>39,179</td>
</tr>
<tr>
<td>Advances to BTL purchasers</td>
<td>3,603</td>
<td>9,903</td>
</tr>
<tr>
<td>House price growth</td>
<td>-5.6%</td>
<td>1.8%</td>
</tr>
<tr>
<td>House price to income ratio</td>
<td>2.3</td>
<td>3.2</td>
</tr>
<tr>
<td>Rental yield</td>
<td>4.8%</td>
<td>5.8%</td>
</tr>
<tr>
<td>Spreads (basis points)</td>
<td>34</td>
<td>81</td>
</tr>
</tbody>
</table>
Correlations – house price growth vs credit growth

Source: Bank calculations.
## Model Validation

<table>
<thead>
<tr>
<th>Core indicator</th>
<th>Experiment</th>
<th>Increase in income by 10%</th>
<th>Increase in credit target by 29%</th>
<th>Increase in housing supply by 7%</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTL LTV</td>
<td>1.00</td>
<td>0.99</td>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td>Owner-occupier LTI</td>
<td>1.01</td>
<td>0.98</td>
<td>1.00</td>
<td></td>
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<tr>
<td>Advances to BTL</td>
<td>0.91</td>
<td>1.33</td>
<td>1.22</td>
<td></td>
</tr>
<tr>
<td>Advances to first-time buyers</td>
<td>0.95</td>
<td>1.00</td>
<td>1.01</td>
<td></td>
</tr>
<tr>
<td>Advances to movers</td>
<td>0.92</td>
<td>1.43</td>
<td>1.00</td>
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<tr>
<td>Debt-to-income ratio</td>
<td>0.90</td>
<td>1.08</td>
<td>1.03</td>
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<tr>
<td>Housing transactions</td>
<td>1.02</td>
<td>1.33</td>
<td>1.01</td>
<td></td>
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<tr>
<td>Interest rate spread</td>
<td>1.00</td>
<td>0.96</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Mortgage approvals</td>
<td>0.92</td>
<td>1.30</td>
<td>1.03</td>
<td></td>
</tr>
<tr>
<td>Owner-occupier debt-to-income</td>
<td>0.90</td>
<td>1.06</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Price-to-income ratio</td>
<td>1.00</td>
<td>0.97</td>
<td>0.97</td>
<td></td>
</tr>
<tr>
<td>Rental yield</td>
<td>0.99</td>
<td>0.97</td>
<td>0.97</td>
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</tbody>
</table>

Source: Bank calculations.
Source: Bank calculations.
Source: Bank calculations.
Emergent cyclical behaviour of house prices
Model Simulation

“Benchmark” expectations

Expectations turned off
Experiment I: Impact of Macro-prudential Policy (LTI Limit)

Source: Bank calculations.
Experiment I: Impact of Macro-prudential Policy (LTI Limit)

Source: Bank calculations.
Experiment I: Impact of Macro-prudential Policy (LTI Limit)

Source: Bank calculations.
Experiment II: Impact of Investors

• Investigating the impact of
  – the number of the investors
  – different types of investors: care about rental yield vs capital gain

  on house price volatility and the amplitude of house price cycles.

• The results indicate that
  • the frequency of large house price movements increases when the number of investors in the market gets larger,
  • the frequency of sharp house price movements and the standard deviation of house price growth are higher when investors are only concerned about capital appreciation.
Simulated Effect of Larger Buy-to-Let/Rental Sector

**Benchmark case**

**Larger buy-to-let market**

Average annual house price growth (%)
(in each boom and bust episode)
Simulated Effect of Larger Buy-to-Let/Rental Sector

All investors put weight only on rental yield

All investors put weight only on capital appreciation

![Histogram of average annual house price growth (in each boom and bust episode)](image1)

![Histogram of average annual house price growth (in each boom and bust episode)](image2)
Conclusions

- ABMs are powerful analytical tools
- They can capture heterogeneity and non-linearities
- They complement other approaches (DSGE, statistical analysis, machine learning) - no substitute
- They require domain knowledge as well as programming expertise
Additional Slides
Household Formation

- There are 10,000 households (2700:1 scale).
- Households enter the model, age, and exit the model.
- Households are formed when children leave home and couples separate.
- Households enter the model with an endowment of income and savings, but no existing housing - they enter either the sales or rental market immediately.
- Household dissolution (‘death’) occurs on death of the last remaining household member.
- On exit, all of a household's financial and housing wealth is given to another, randomly chosen, household which is still in the model.
Household Income

- New HHs are assigned to an income from the empirical distribution of incomes for that age.
- They remain in that percentile of the income distribution for the rest of their life.
- Hence, there are no idiosyncratic income or unemployment shocks.
Renters decide whether to buy or rent again when their lease expires.

Successful sellers decide whether to rent or buy again (but mostly they'll buy again).

The probability of deciding to rent or buy is given by a logistic curve, based on the cost of renting against the cost of mortgage payments and expected capital appreciation of the house.
Becoming a Renter

• A household will enter the rental market if it has sold its home and was not successful in buying another home.
• A current renter will re-enter the rental market when a rental contract ends and they decide not to buy a house.
• If a household decides to rent, they will bid 0.3 times their income for rent.
Becoming a Buy-to-Let (BTL) Investor

• 8 percent of HHs whose income percentile is above 50 percent are given a BTL gene (overall 4 percent of BTL investors in the population).

• Owner-occupiers with a BTL gene decide to buy houses based on the expected yield and expected capital gain of the best performing house quality on the market.

• Different investors put different weight on these two income streams.

• The sum of the weighted streams is passed through a logistic function to get a probability of bidding on houses.
Landlords

• A household that owns a buy-to-let house will put it on the rental market whenever a rental contract ends, or when a new buy-to-let house is bought that doesn't already have a tenant.

• The length of a rental agreement is chosen randomly from 12 to 24 months with uniform probability. This is based on figures from ARLA.

• A BTL property cannot be rented if it is on sale.

• The rent BTL investors charge is a function of the average marked-to-market rental price of houses of this quality, and the average days on the market. If a house on the rental market does not get filled, the price is multiplied by 0.95 each month.
Desired Leverage

- On buying a house, if the household has liquid wealth of twice the price of the house, they will pay outright.
- If they are BTL investors they will choose from a Gaussian distribution, calibrated against data.
- Otherwise they will choose the i-th percentile from a log normal distribution (parameters depending on whether they are FTB or OO), where i is their income percentile.
Listing

• Owner-occupiers: They sell with a fixed probability (on average every 11 years, calibrated against English Housing Survey).

• BTL investors: They decide to sell houses in their current portfolio based on the realised interest coverage ratio of that house and the expected capital gains on the house. BTL investors differ in the weightings they assign to these two streams of income. The weighted sum of these streams is then passed through a logistic function to give a probability for deciding to sell the house.

• Houses are offered on the market at a price, which is a function of the average sold-price of houses of this quality.
Price Reductions and De-listing

- If a house remains on the market from the previous time-step, with a 6 percent probability its price is reduced by an amount drawn from a Gaussian distribution - calibrated against data on house price reductions from Zoopla.
- If the price drops below the amount needed to pay the mortgage on the house, it is withdrawn from the market.