The Challenge of Agent-based Modeling in Economics

ESRC Conference on Diversity in Macroeconomics
University of Essex

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The talk I almost gave:

"Three diverse approaches to modeling systemic risk"

- Cascading failure network models
  - interbank lending
  - overlapping portfolios
  - combination of the two
- Dynamical systems models
  - Liquidation-based accounting
  - leverage and overlapping portfolios revisited
- Agent-based models
  - leveraged value investors
  - housing model
  - CRISIS (model of "main components" of economy

(appeared in Complex Systems, 2009)

The Virtues and Vices of Equilibrium, and the Future of Financial Economics

J. Doyne Farmer* and John Geanakoplos†

January 11, 2008

Abstract

The use of equilibrium models in economics springs from the desire for parsimonious models of economic phenomena that take human reasoning into account. This approach has been the cornerstone of modern economic theory. We explain why this is so, extolling the virtues of equilibrium theory, then present a critique and describe why this approach is inherently limited, and why economics needs to move in new directions if it is to continue to make progress. We stress that this shouldn't be a question of dogma, but should be resolved empirically. There are situations where equilibrium models provide useful predictions and there are situations where they can never provide useful predictions. There are also many situations where the jury is still out, i.e., where so far they fail to provide a good description of the world, but where proper extensions might change this. Our goal is to convince the skeptics that equilibrium models can be useful, but also to make traditional economists more aware of the limitations of equilibrium models. We sketch some alternative approaches and discuss why they should play an important role in future research in economics.

Paul Krugman's view of agent-based modeling

"Oh, and about ~~Roger~~Doyne Farmer (sorry, Roger!) and Santa Fe and complexity and all that: I was one of the people who got all excited about the possibility of getting somewhere with very detailed agent-based models — but that was 20 years ago. And after all this time, it's all still manifestos and promises of great things one of these days."

Paul Krugman, Nov. 30, 2010, in response to an article about INET housing project in WSJ.

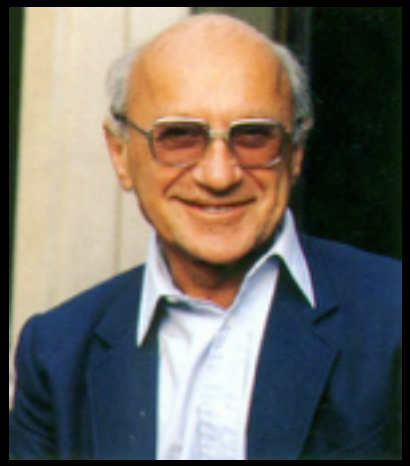
Reminder: All economics models are agent-based models

- ABMs are *computational* agent-based models (ACE)

Why isn't ABM the mainstay of economics?

- Math culture is deeply rooted
  - papers scored too much on math vs. science
  - disdain and distrust of simulation
  - fascination with rationality and optimality
- ABM is a fringe activity, hasn't delivered home runs needed to enter establishment
  - chicken/egg problem
- Lucas critique

Lucas Critique



- Recession of 70's. "Keynesian" econometric models.
- Phillips curve: Rising prices ~ rising employment
- Following Keynesians, Fed inflated money supply
- Result: Inflation, high unemployment = stagflation
- Problem: People can think
- Conclusion: Macro economic models must incorporate human reasoning
- Solution: Dynamic Stochastic General Eq. models

Advantages of DSGE

- "Micro-founded" (unlike econometric models)
  - can be used for policy analysis.
- Time series models
  - initializable in current state of the world, can make conditional forecasts
- Describe a specific economy at a specific time.
- In some sense parsimonious

Why agent-based modeling?

- Diversifies toolkit of economics: Complements DSGE and econometric models. Also microfounded
- Time is ripe: increased computer power, Big Data, behavioral knowledge. Never let a crisis go to waste.
- Hasn't really been tried yet -- crude estimates:
  - econometric models: 30,000 person-years
  - DSGE models: 20,000 person-years
  - agent-based models: 500 person-years
- Successes elsewhere: Traffic, epidemiology, defense
- Examples of successes in economics:
  - Endogenous explanations of clustered volatility and heavy tails; firm size; neighborhood choice

Advantages

- Can faithfully represent real institutions
- Easily captures instabilities, feedback, nonlinearities, heterogeneity, network structure,...
- Shocks can be modeled endogenously
- Easy to do policy testing
- Easy to incorporate behavioral knowledge
- Can calibrate modules independently using micro data -- much stronger test of models!
  - In some sense between theory and econometrics
- ABMs synthesize knowledge:
  - Possible to understand what is not understood

Challenges

- Little prior art
- Developing appropriate abstractions

– What to include, what to omit?

– How to keep model simple yet realistic?

- Micro-data to calibrate decision rules?
- Data censoring problems
- Realistic agent-based models are complicated.
- No theoretical foundation

Cautionary tale of weather forecasting

Formulating decision rules

- Make something up
- Take from behavioral literature
- Perform experiments in context of ABM
- Interview domain experts
- Calibrate against microdata
- Learning and selection, Lucas critique

(ABM can respond to Lucas critique)

Existing ABMS in economics

- Almost all are qualitative
- Range of complexity, e.g.
  - zero/low intelligence continuous double auction
  - latent order book (Bouchaud group)
  - Lebaron, Brock Hommes trend follow/fundamentalist
  - Axtell firm size
  - Thurner et al. leveraged value investors
  - SFI Stock Market
  - Dosi-group
  - EURACE

Is it possible to make a quantitative ABM that can be used as a time series model?
(and therefore can compete with DSGE)

Housing model project

- Senior collaborators: Rob Axtell, John Geanakoplos, Peter Howitt
- Junior collaborators: Ernesto Carella, Ben Conlee, Jon Goldstein, Matthew Hendrey, Philip Kalikman
- Funded by INET three years ago for $375,000.

Agent-based model of housing market

- Goal: conditional forecasts and policy analysis
- Simulation at level of individual households
- Exogenous variables: demographics, interest rates, lending policy, housing supply.
- Predicted variables: prices, inventory, default
- 16 Data sets: Census, mortgages (Core Logic),tax returns (IRS), real estate records (MLA), ...
- Current goal: Model Washington DC metro area
- Future goal: All metro areas in US

Module examples

- Desired expenditure model
  - buyers' desired home price as a function of household income and wealth
- Seller's pricing model
  - seller's offering price as a function of home quality, time on market, and total inventory
- Buyer-seller matching algorithm
  - links buyers and sellers to make transactions
- Household wealth dynamics
  - models consumption and savings
- Loan approval
  - qualifies buyers for loans based on income, wealth; must match issued mortgages

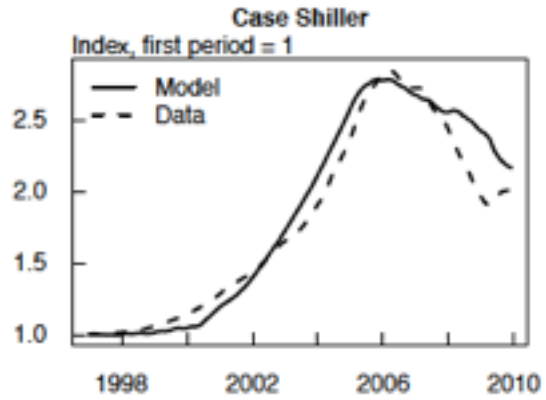
Housing model algorithm

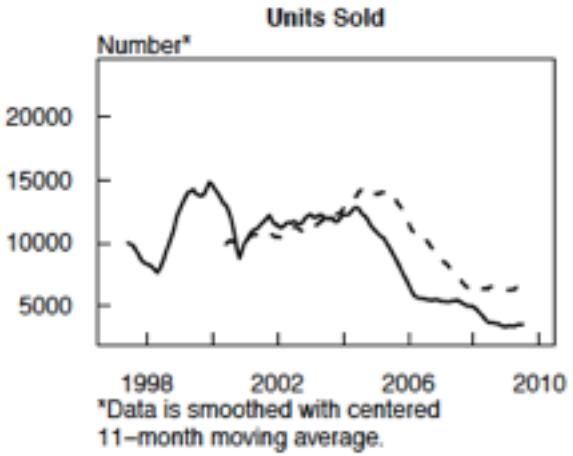
At each time step:

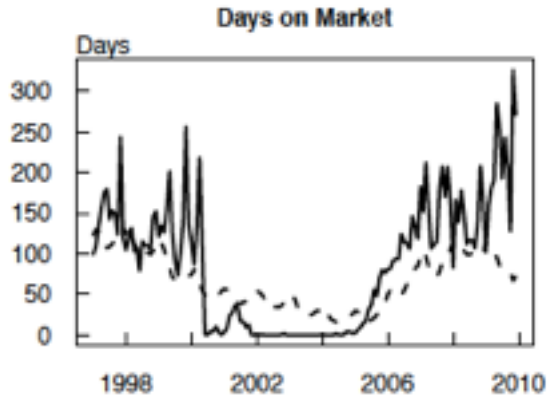
- Input changes to exogenous variables
- Update state of households
  - income, consumption, wealth, foreclosures, ...
- Buyers:
  - Who? Price range? Loan approval, terms?
- Sellers:
  - Who? Offering price? Price updates?
- Match buyers and sellers
  - Compute transactions and prices

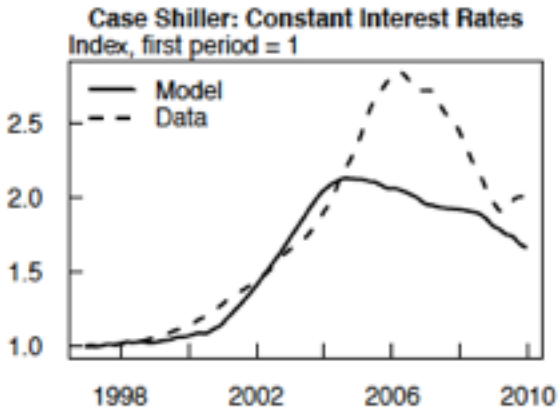
Results when we fit parameters to match the target data

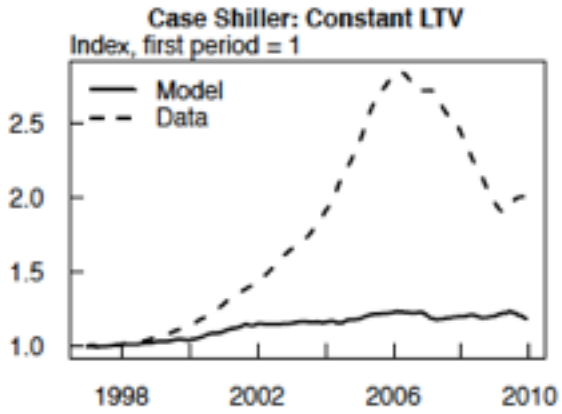
Results obtained by hand-fitting parameters

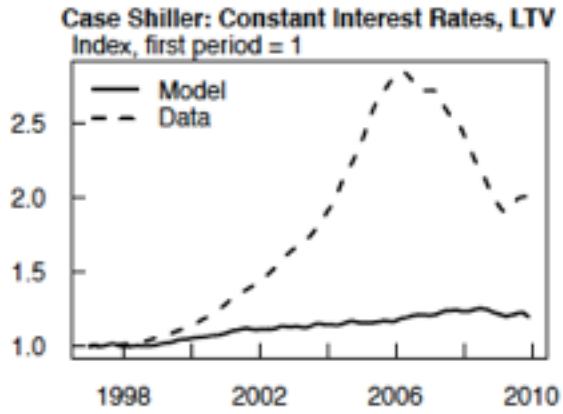












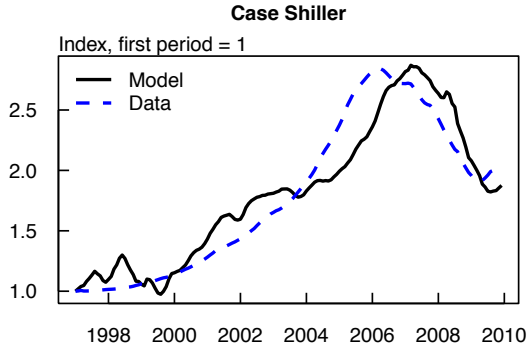
(this is an early slide)

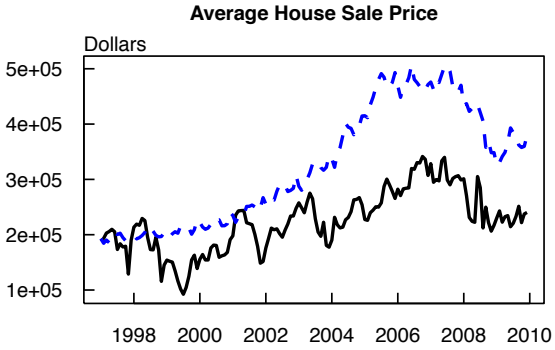
Tentative conclusion: Lending policy is dominant cause of housing bubble in Washington DC.

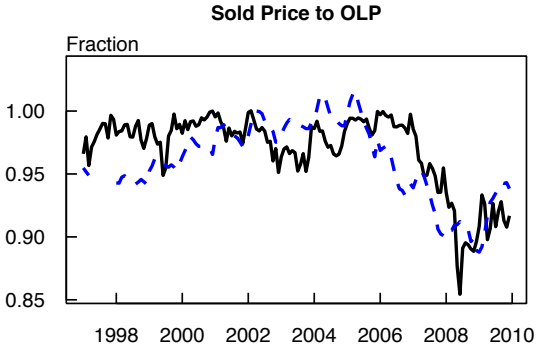
Results when we fit each module separately on data that is not the target data.

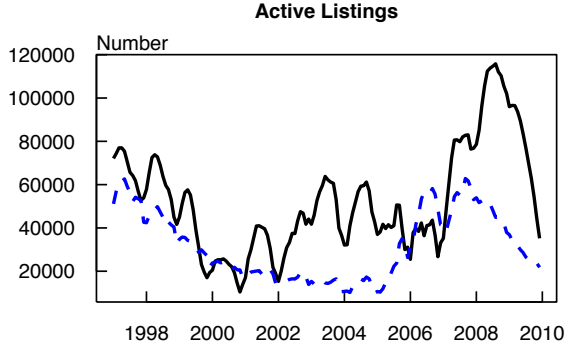
Baseline result

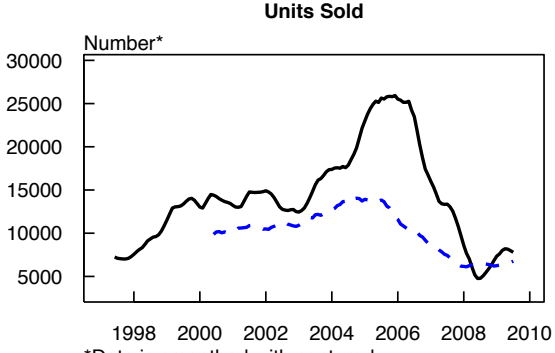
Housing Market Results











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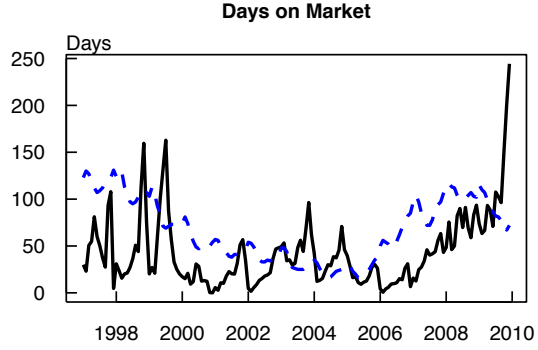
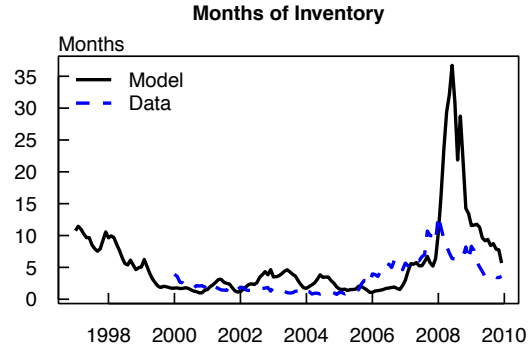
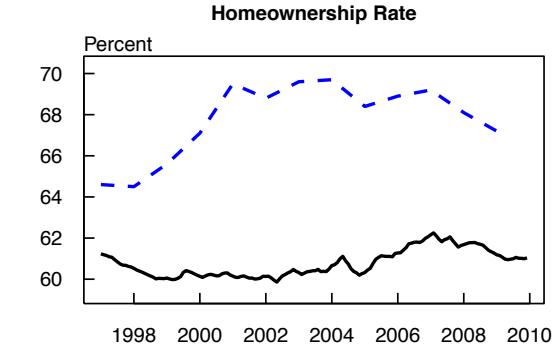
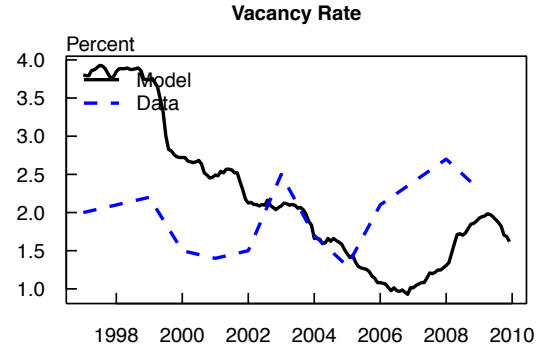




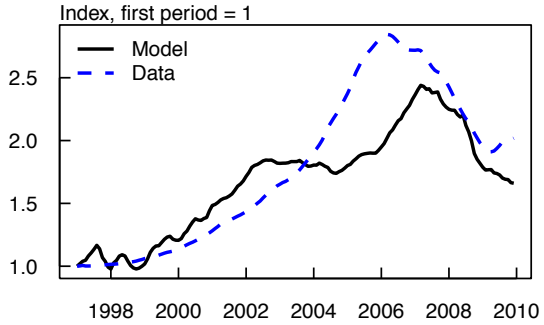




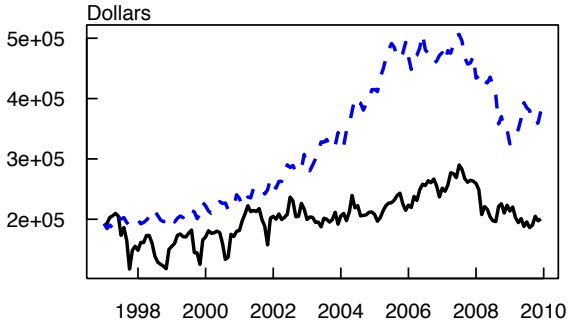
fixed interest rate

Housing Market Results

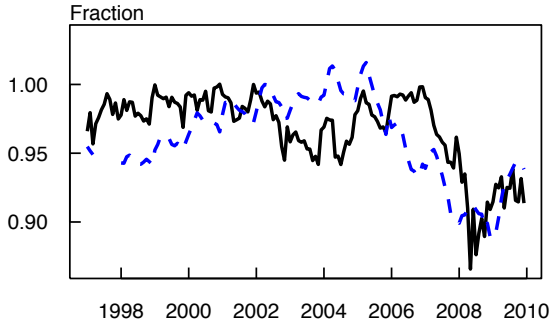
Case Shiller



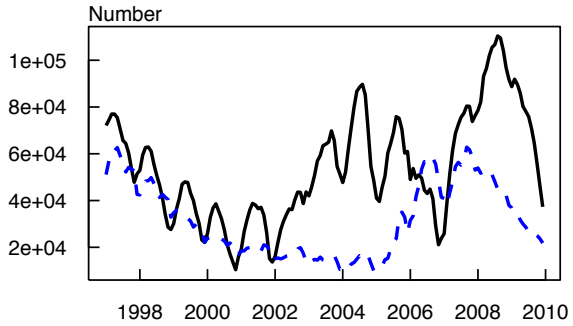
Average House Sale Price



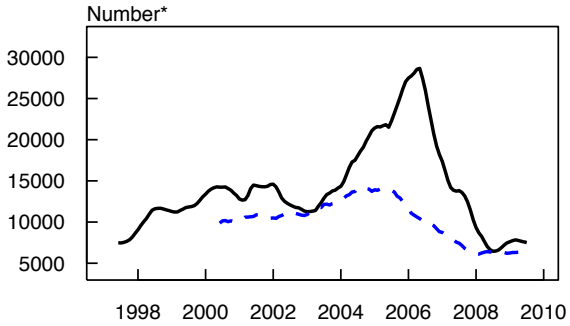
Sold Price to OLP



Active Listings



Units Sold



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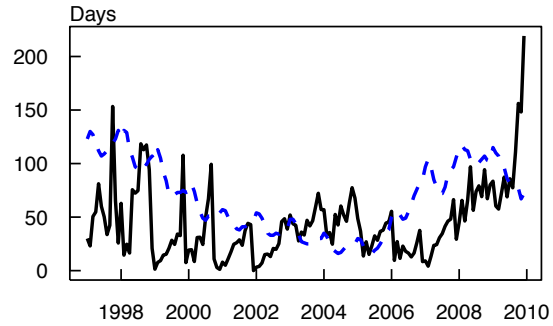
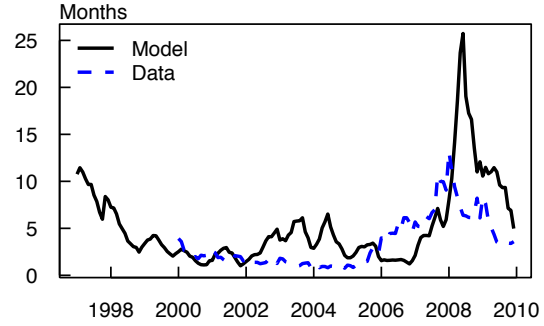
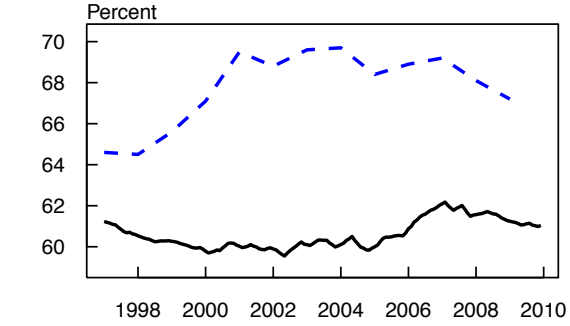
Days on Market



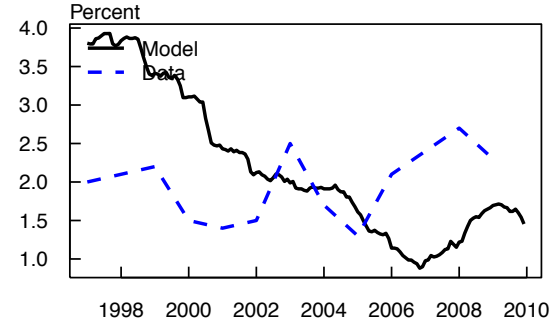
Months of Inventory



Homeownership Rate



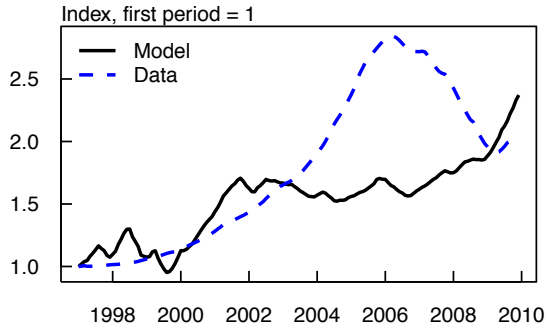
Vacancy Rate



fixed lending policy

Housing Market Results

Case Shiller



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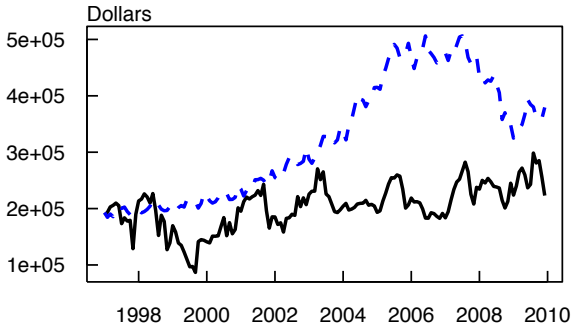

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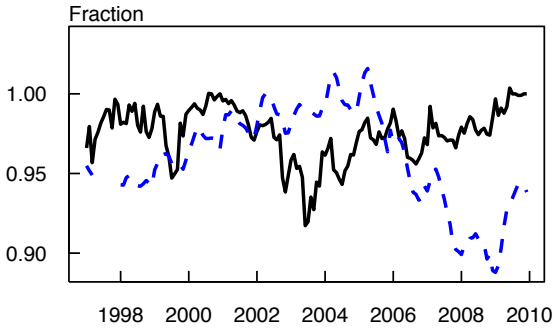

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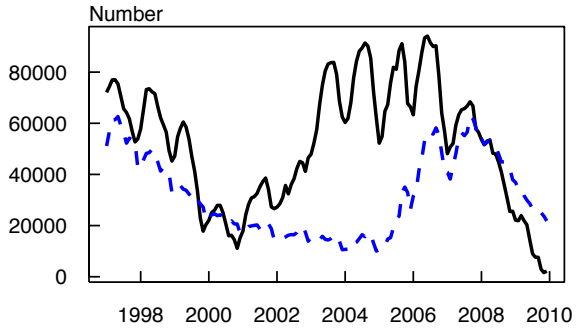
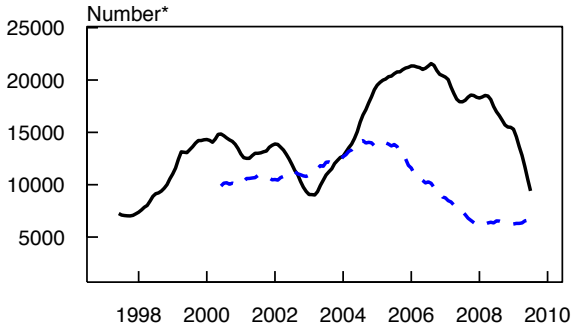


Units Sold



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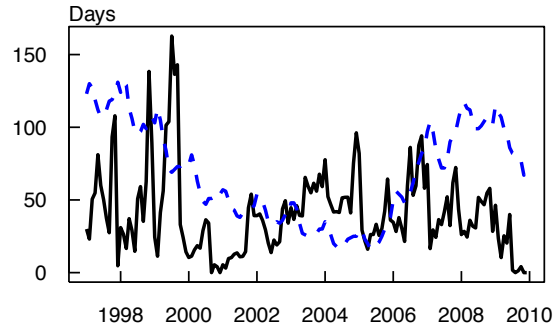

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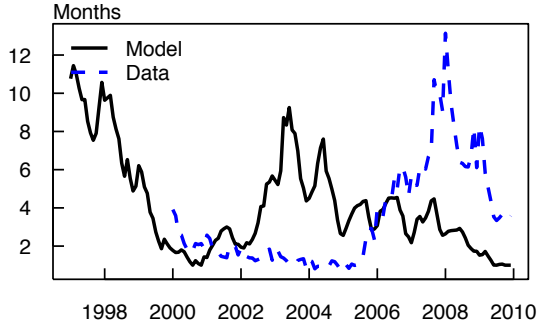

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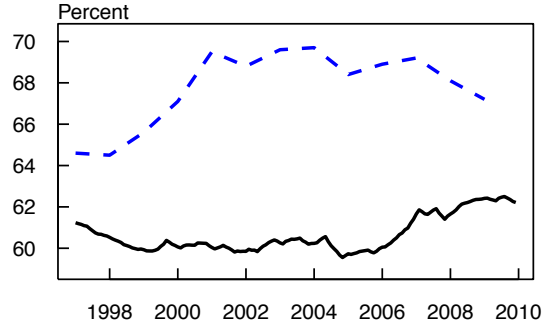
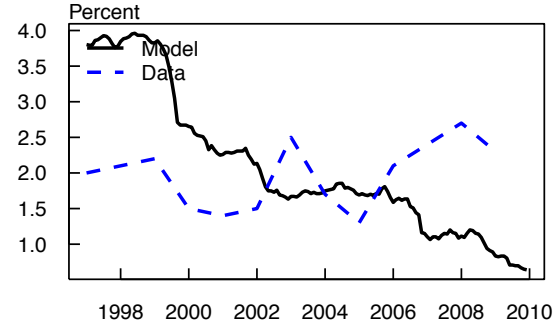
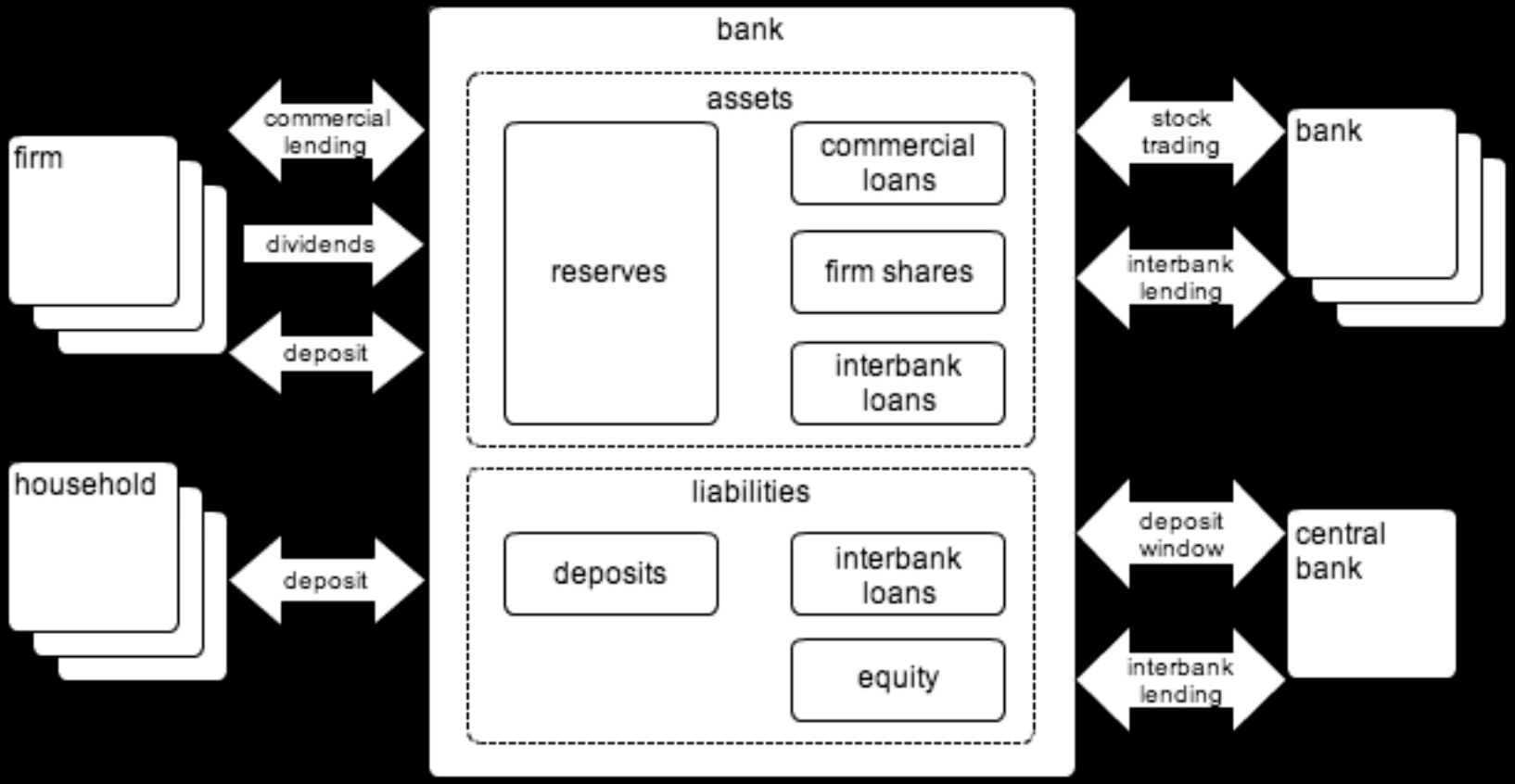


Vacancy Rate



- Complete agent-based model of economy
- Agents: Households, firms, banks, mutual funds, central banks. Both financial and macro.
- Goals:
  - tool for policy decision making
  - series of models of increasing complexity
  - create standard software library
  - Be useful for central banks

CRISIS schematic



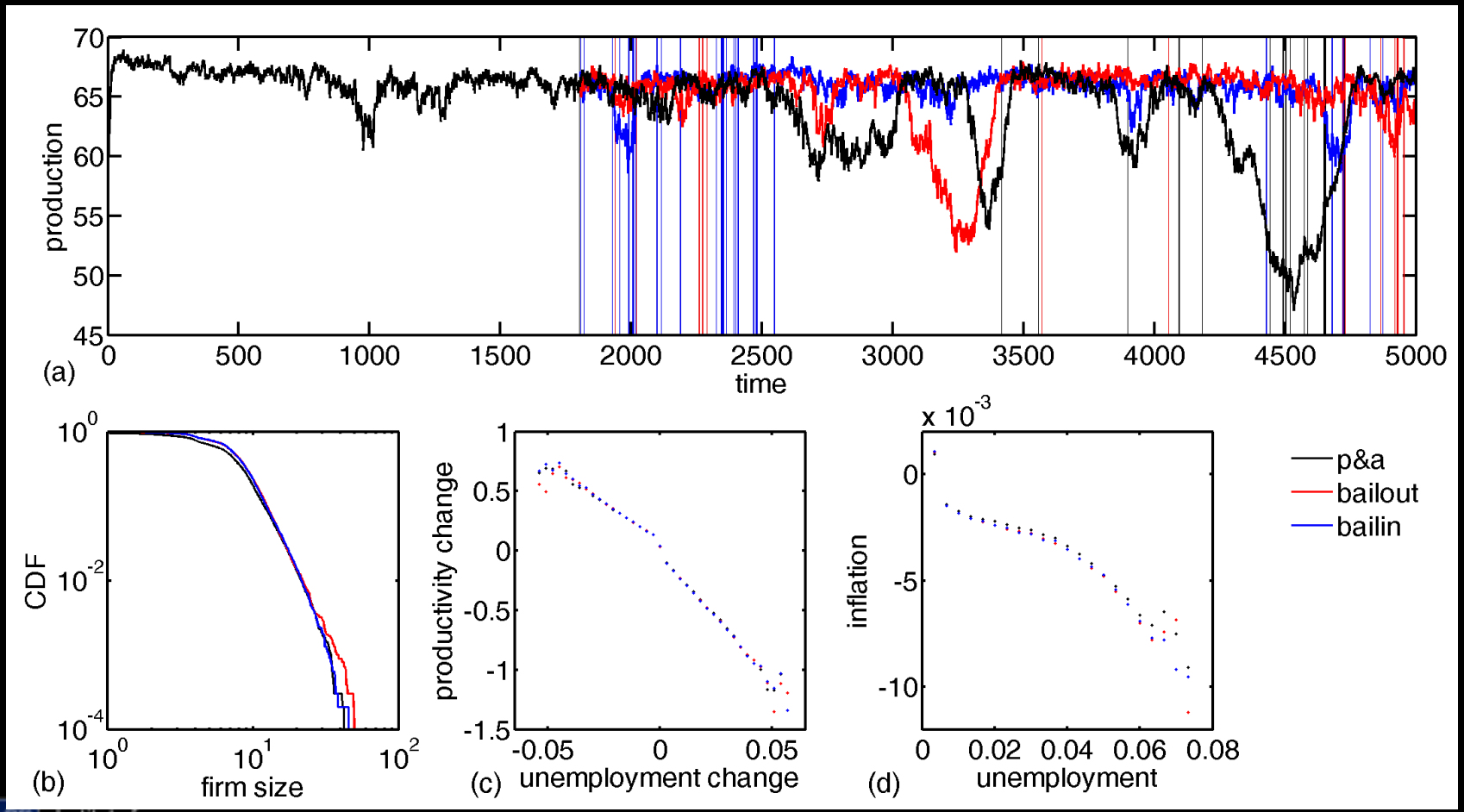
Production sector

- Input-output economy
  - firms are myopic profit maximizers that use heuristics to set price and quantity of production
  - variable labor supply
  - finance production via mixture of credit and equity
  - input-output structure mimicking real economy
- For comparison have simpler alternatives, e.g. fixed labor Cobb Douglas, exogenous dividends.

Financial sector

- Banks
  - take deposits from firms and households, lend to firms, buy and sell shares, participate in interbank market.
  - Investment strategies: trend following, fundamental
- Central bank
  - conventional and unconventional policy operations
  - interest rate can be formed endogenously
- Firms
  - borrow from banks to fund production

Unconventional policy operations: purchase & assumption, bailout, bail in



Conclusions

- We have lots of work to do to make models that can seriously compete with DSGE
- Should be possible to make model with rich institutional structure, calibrated to real world
- Capability to put an economy in current state of a real economy, make conditional forecasts
- Economic models of future will be ABM
  - but when?
- Chicken-egg problem to get ABM off the ground

Conclusions

- Must respect institutional structure
  - Impossible to do everything at once: often in conflict with understanding strategic reasoning
  - danger of strict requirement for "economic content"
- Fundamental problem in macro is lack of data
  - only hope is ABM with microdata calibration
- Want different tools for different jobs — *diversity*
  - simple models for understanding mechanism
  - richer models for quantitative understanding

Economics needs to allow more diversity!

Future versions will include:

- Mortgage markets
- Realistic input-output structure
- Derivative markets
- Bond markets
- Shadow banking system

Design philosophy

- As simple as possible (but no more)
- Design model around available data
- Fit modules and agent behaviors independently from target data, using several different methods:
  - micro-data for calibration and testing
  - consult domain experts for behavioral hypotheses
  - adaptive optimization to cope with Lucas critique
  - economic experiments
- Systematically explore model sensitivities
- Plug and play
- Standardized interfaces
- Industrial code, software standards, open source