Bounded Rationality

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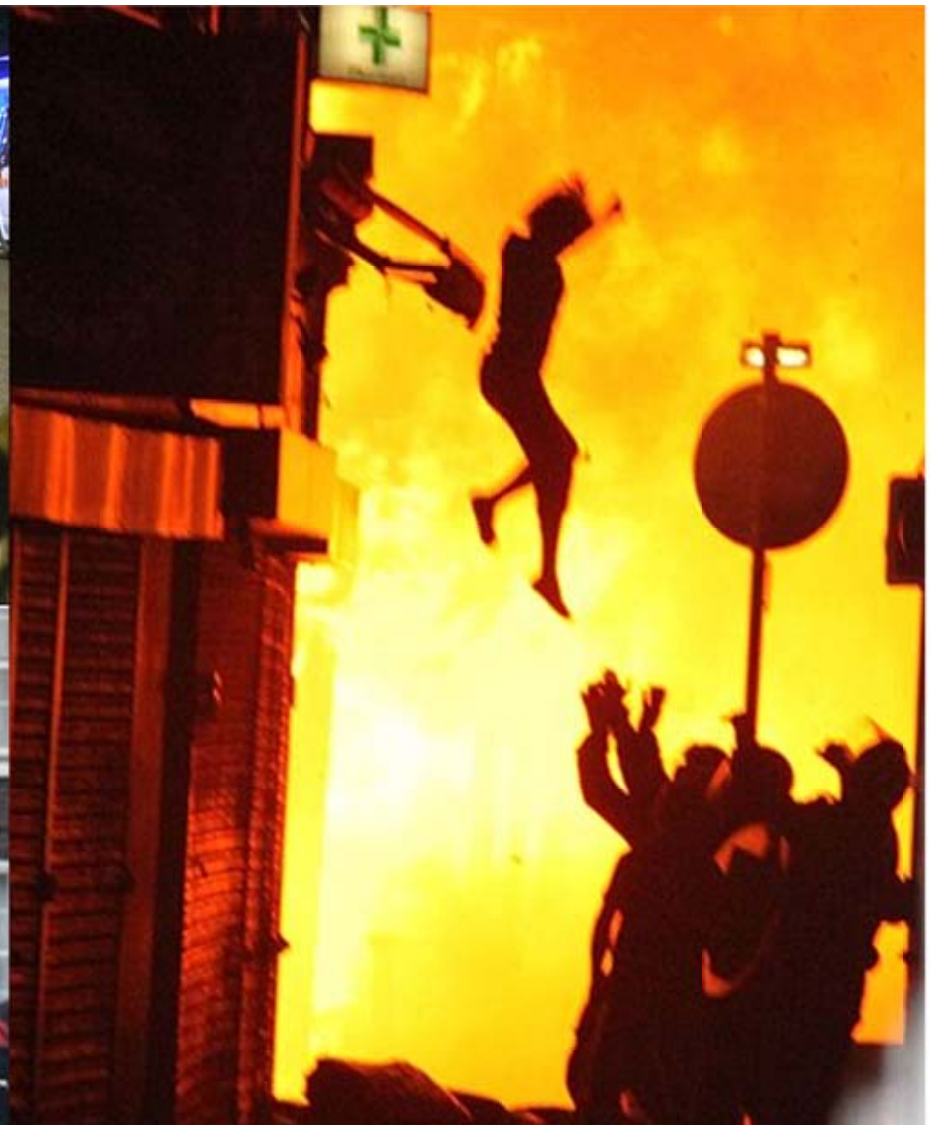
Overview

1. Human behavior and rationality?
   - a whole bunch of observations
2. Do these observations matter for economic analysis?
3. Ways to go forward (next slide)
4. Numerical tools:
   - algorithm to solve models with both rational and boundedly rational agents
     and we will do it the right way !!!
5. My humble attempt to be transparent in the "wilderness"

Ways to go forward

- Alternative preferences
  - "Dual self" model of Fudenberg and Levine
  - Hyperbolic discounting (Thaler, Laibson and others)
  - Recursive utility (Epstein and Zin)
- Robust control (Hansen and Sargent)
- Bounded rationality
  - learning
  - agent-based models
  - replace full optimization with H. Simon's "satisfying"
    - my interpretation of Branch, Evans, & McGough
  - rule of thumb agents
  - prospect theory (Kahneman)
    - boundedly rational because preferences depend on framing

Rational agents?



Hamlet: "What a piece of work is a man! how noble in reason! how infinite in faculties!
Hamlet, II.2.319

Puck: "Lord, what fools these mortals be!"
Midsummer Night's Dream, III.3.116

(From John Conlisk's 1996 survey paper)

People don't understand probabililty

- **Question**: If a test to detect a disease whose prevalence is 1/1000 has a false positive rate of 5%, what is the chance that a person found to have a positive result actually has the disease?

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- **Question**: If a test to detect a disease whose prevalence is 1/1000 has a false positive rate of 5%, what is the chance that a person found to have a positive result actually has the disease?

- **Oberved answer:** often 95%

People do understand probability

Maybe the question wasn't asked right:

- **Question**: 1 out of every 1000 Americans has disease X. A test has been developed to detect when a person has disease X. Every time the test is given to a person who has the disease, the test comes out positive. But someties the test also comes out positive when it is given to a person who is healthy. Specifically, out of every 1000 perople who are helathy, 50 of them test positive for the disease.

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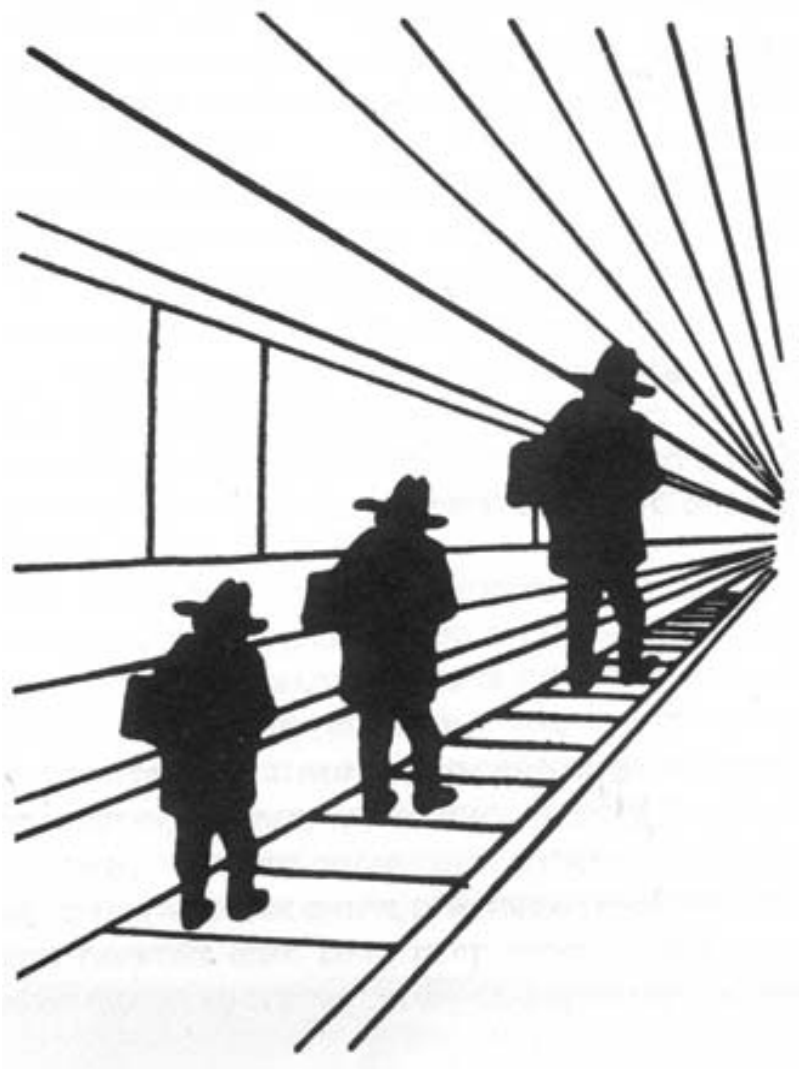
- **Correct answer:** around 76%
  See Samuels, Stich, & Bishop for more info and references

Which of the three figures is the largest?



From Kahneman (2003)

Behavior and uncertainty

Gamble A:
25 with prob 0.33
24 with prob 0.66
0 with prob 0.01

Gamble B: 24 with prob 1

Gamble C:
25 with prob 0.33
0 with prob 0.67

Gamble D:
24 with prob 0.34
0 with prob 0.66

Allais paradox

- Lab evidence: B $\succ$ A and C $\succ$ D
- But A-B choice versus the C-D choice is like having payoffs in one node replaced
  shouldn't matter since *expected* utility is additive
- B $\succ$ A and C $\succ$ D implies preference reversal

Same choices written differently

Gamble A:
25 with prob 0.33
24 with prob 0.66
0 with prob 0.01

Gamble B:
24 with prob 0.66
24 with prob 0.34

Gamble C:
25 with prob 0.33
0 with prob 0.66
0 with prob 0.01

Gamble D:
0 with prob 0.66
24 with prob 0.34

Framing & past matters

- price for getting mug $<$ price for selling mug
- default for "signing up" or ”opting out" of pension plan matters

Framing & past matter

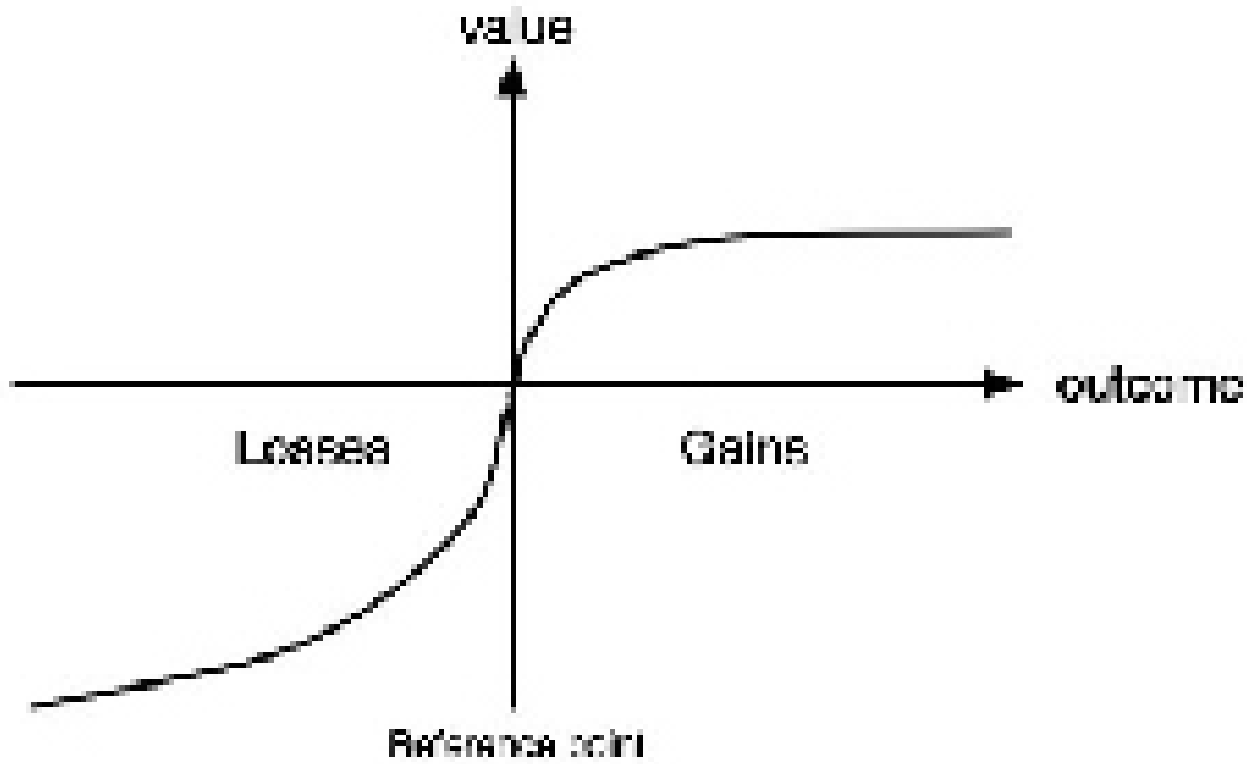
Questions to college students

1. How happy are you with your life in general?
2. How many dates did you have in the last month?

Answers depend on order questions are asked

(See Kahneman 2003)

Prospect theory



- $\Delta v / \Delta x$ bigger for losses than for gains
- Insurance:
  - sharp loss to pay premium
  - value of big loss undervalued
  - $\Longrightarrow$ insurance may not be optimal

Some questions for you

- If people are as smart as rational agents in our model, then

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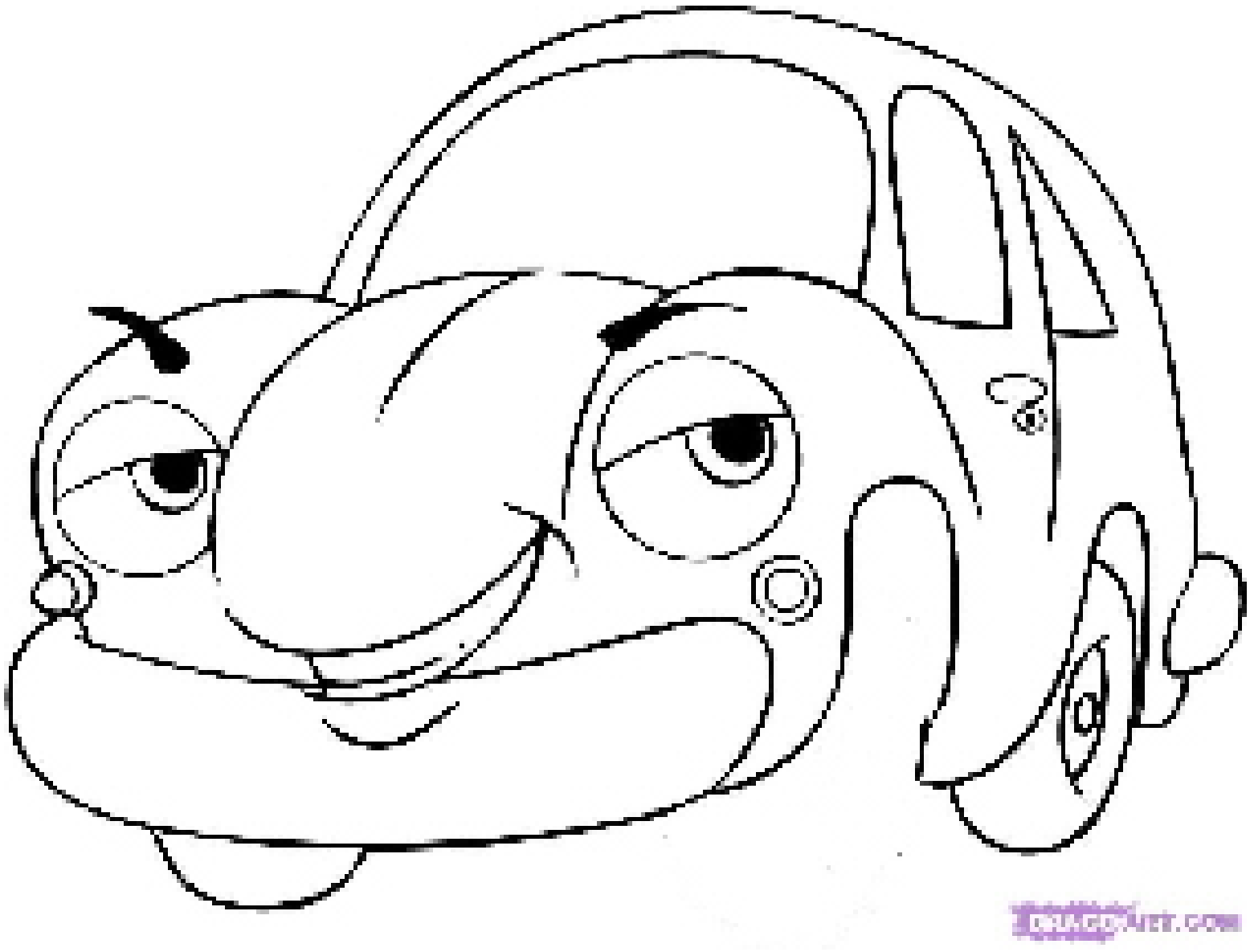
- If people are as smart as rational agents in our model, then
- why do *you* need to be taught about how to solve models?
- why do so many students fail to get perfect scores?

What did I change in the pic below?



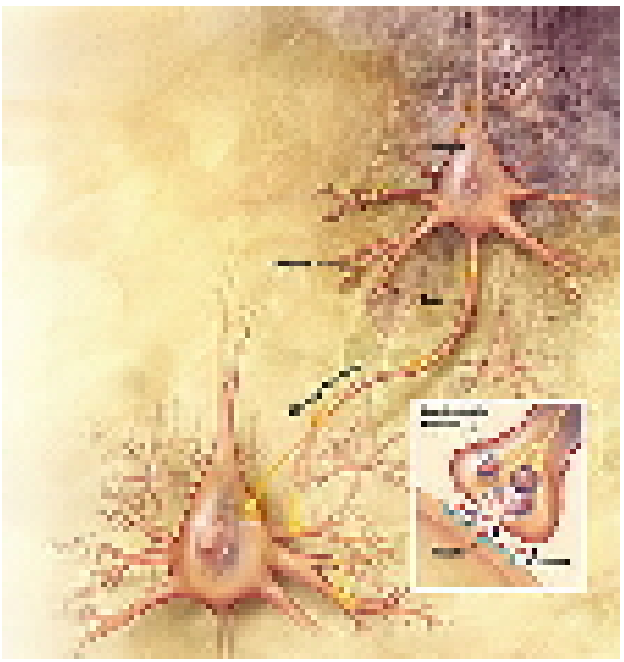
People are not that dumb

- Brain can solve very complex tasks quickly
  - e.g. face recognition, recognizing emotions, speaking languages
  - play chess
  - create beautiful music (well some brains)
- Evolutionary psychology: it is singularly implausible that our species would have evolved with no "instinct for probability" and, hence, be "‘blind to chance"

  (see Samulels, Stich, Bishiop 2002 and references)

How come our brains works so well

- Speed of neurons is much slower than computer chip
  - million times slower!
- But they form a very powerful network (neural net)



Different types of choices approached differently

Kahneman distinguishes two modes of thinking and deciding:

1. reasoning, e.g. when we you are asked to computer 17×258
2. intuition, e.g., when we are hesitant to eat a chocolate in the shape of a cockroach

But even when solving more complex tasks humans use heuristics/intuition

Using heuristics

From Frederick (2003):

- A bat and a ball cost \$1.10 in total.

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Using heuristics

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- A bat and a ball cost \$1.10 in total.
- The bat costs \$1 more than the ball.
- How much does the ball cost?
- Very common (wrong) answer: \$0.10.

Using heuristics

- The use of heuristics is a likely source for systematic bias
- But heuristics can also be an efficient way to make quite good decisions, especially after practice
  - teacher in detecting cheating
  - a detective when interviewing a suspect
  - a salesman when selling a product
  - a pickpocket searching for a victim

Facts about stuff we try to explain

Asset pricing puzzles:

- Equity premium puzzle
  - both level and time-variation
- Fama French factors
  - market risk not only thing that is being priced
- Excess volatility puzzle
  - stock price to volatile given volatility earnings
- IPO underpricing puzzle
  - sharp increases after going public
- Home bias puzzle
  - investors don't diversify abroad

Don't be as dumb as media "academics"

- Efficient markets $\equiv$ stock prices reflect available information
- Efficient markets $\neq$ stock prices only affected by fundamentals

Rational bubble

- Risk neutral agents
- Excess return r_{t+1}:

$$r_{t+1} = \begin{cases} +1\% \text{ with probability } 0.95 \\ -19\% \text{ with probability } 0.05 \end{cases}$$

- Expected excess return:

$$\mathsf{E}\left[r_{t+1}\right] = 0$$

Does it matter?

- Summary of the above: There is ample evidence that agents are not "that smart" and that deviations from rationality can be systematic.

- What to conclude?
  - Obviously, models with rational expectations are not perfect, but
  - are they useless?
  - don't they provide a useful approximation?
  - should they be at least be the starting point?
  - are they maybe still the best we have?

"As if" argument

Friedman's "The methodology of Positive Economics":

- You should test the implications of the theory not the assumptions of the theory itself
- If the implications of a theory regarding the choices you are interested in are correct, then it is a useful theory

Dutch total football

Arnold Muhren: Before I had the ball I knew exactly what I would do with it. I always knew two or three moves ahead. Before I get the ball I can already see someone moving in front of me, so when the ball arrives I don't have to think about it. … English players don't think until they have the ball at their feet.

In Winner (2000)

Dutch total football

To get some idea about what it is watch:

`http://www.youtube.com/watch?v=OK3RUt7BZWI`

"As if" argument

Heisenberg's "Uncertainty Principle" seems bizarre, non-intuive, non-understandable, & hard to believe

but it seems to work very well

See: `http://www.youtube.com/watch?v=KT7xJ0tjB4AI`

"As if" argument

- Especially in finance, predictions of REE models not that great.
- What if REE leads to multiple predictions (multiple equilibria)?
- What type of theory is likely to lead to more correct implications/predictions?

"Rationals dominate" argument

- Shouldn't irrational agents be driven into nonimportance?

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- Conlisk: argument works less well for indivuals:
  "we seldom read in the obituary pages that people die of suboptimization"

"Rationals dominate" argument

- Shouldn't irrational agents be driven into nonimportance?
- Conlisk: argument works less well for indivuals:
  "we seldom read in the obituary pages that people die of suboptimization"
- So at least for things like unemployment irrational agents should matter

"Rationals dominate" argument

- But shouldn't irrational agents at (a lot) less wealthy $\Longrightarrow$ less important
- Model of DeLong, Schleifer, Summers, Waldman (1990):
  - noise traders bear a larger amount of the risk (they create themselves)
  - $\Longrightarrow$ earn a higher expected return
- Trading against "the dumb" may require a long horizons and deep pockets to make margin calls

"Rationals dominate" argument

Keynes in The General Theory:
"If the reader interjects that there must surely be large profits to be gained... in the long run by a skilled individual who... purchase[s] investments on the best genuine long-term expectation he can frame, he must be answered... that there are such serious-minded individuals and that it makes a vast difference to an investment market whether or not they predominate...

But we must also add that there are several factors which jeopardise the predominance of such individuals in modern investment markets. Investment based on genuine long-term expectation is so difficult... as to be scarcely practicable. He who attempts it must surely... run greater risks than he who tries to guess better than the crowd how the crowd will behave."

"Transparancy" argument

- Rational expectations: clear what you are doing
- Bounded rationality: wilderness (according to Chris Sims in 1980)

"Aggregation" argument

- The aggregate behavior may very well be approximately accurate
  - evidence of counting pennies experiment is impressive
- But what is the aggregate?
  - representative agent with same preferences?
  - representative agent with different preferences?
  - can you aggregate?
    - probably not exactly (e.g. Arrow's impossibility theorem)
    - maybe approximately?

Right type of theory for different questions?

What theory to use probably should depend on what you want to do:

- Predict responses to policy changes or explain already observed behavior.
- Match data or do thought experiments?

How to go from here:

Herbert Simon in a letter to Rubinstein:

"At the moment we don't need more models; we need evidence that will tell us what models are worth bulding and testing"

From Rubinstein (1998)

How to go from here:

1. Other types of preferences
2. Robust control
3. Bounded rationality

Bounded rationality

1. Learning:
   Sargent: let agents in economic models operate like the econometricians that estimate them
2. Add rules of thumb agents
3. Agent-based modelling (more on this below)
4. Satisfying instead of optimizing (more on this below)
   - Branch, Evans, & McGough
5. Combination (more on this below)

Agent-based models

Very simple setup

1. Specify simple rules for agents' behavior
2. Simulate

- Computationally much easier than algorithms to solve models with forward looking agents
- You can still get fascinating (sometimes complex) dynamics for system as a whole

Example: Game of Life

Environment:
squares like on a chess board
Elements:
An agent is a square
Status
An agent is dead or alive
Definition:
Neighbor: the *eight* surrounding cells

Example: Game of Life

Rules:

1. live cell & # of neighbors $> 3 \Longrightarrow$ death
2. live cell & # of neighbors $< 2 \Longrightarrow$ death
3. live cell & # of neighbors $= 2$ or $3 \Longrightarrow$ survive to the next period
4. dead cell & # of neighbors $= 3 \Longrightarrow$ resurrection

Example: Game of Life

Playing the game

Each period check the rules for each cell simultaneously

Example: Game of Life

Patterns that can be generated?

- Lots
- All depends on initial condition

Brock & Hommes model of asset prices

- **Environment:** very very simple
- **Results:** ranging from (close to) REE to chaotic

Environment

- Agents only care about expected returns and variance
- Demand for risky asset by agent of type i:

$$s_{i,t} = \frac{\mathrm{E}_{i,t}\left[p_{t+1} + d_{t+1} - (1+r)\,p_t\right]}{\gamma\sigma^2}$$

$$d_t \text{ is i.i.d. and } \mathrm{E}_t d_{t+1} = \bar{d}$$

- Variance is assumed and known to be constant
- Equilibrium:

$$\sum_{i=1}^{I} w_{i,t} s_{i,t} = S$$

$w_{i,t}$: fraction of agents of type i

Rational Expectations Equilibrium

$$p_t^{\text{REE}} = p^{\text{REE}} = \frac{\bar{d}}{r}$$

Forming beliefs

Beliefs are "chosen" from a set of beliefs. Examples:

- Fundamentalist:

$$\mathsf{E}_t\left[p_{t+1}\right] = \mathsf{E}_t\left[p^*_{t+1}\right] = p^{\mathsf{REE}}$$

  This guy is definitely *not* rational!!!

- Extrapolators:

$$\mathsf{E}_t\left[p_{t+1}\right] = p^{\mathsf{REE}} + \alpha\left(p_{t-1} - p^{\mathsf{REE}}\right)$$

Evolutionary selection of beliefs

- Agents' beliefs are chosen randomly
- Probability of switching to strategy i is increasing with profitability of strategy i

Evolutionary selection of beliefs

- "Fitness" of strategy i :

$$U_{i,t} = \omega\left(\left(p_t + d_t - (1+r)\,p_{t-1}\right)s_{i,t-1} - \phi_i\right) + (1-\omega)U_{i,t-1}$$

where ϕ_i is the cost of strategy i

- Evolutionary development of types:

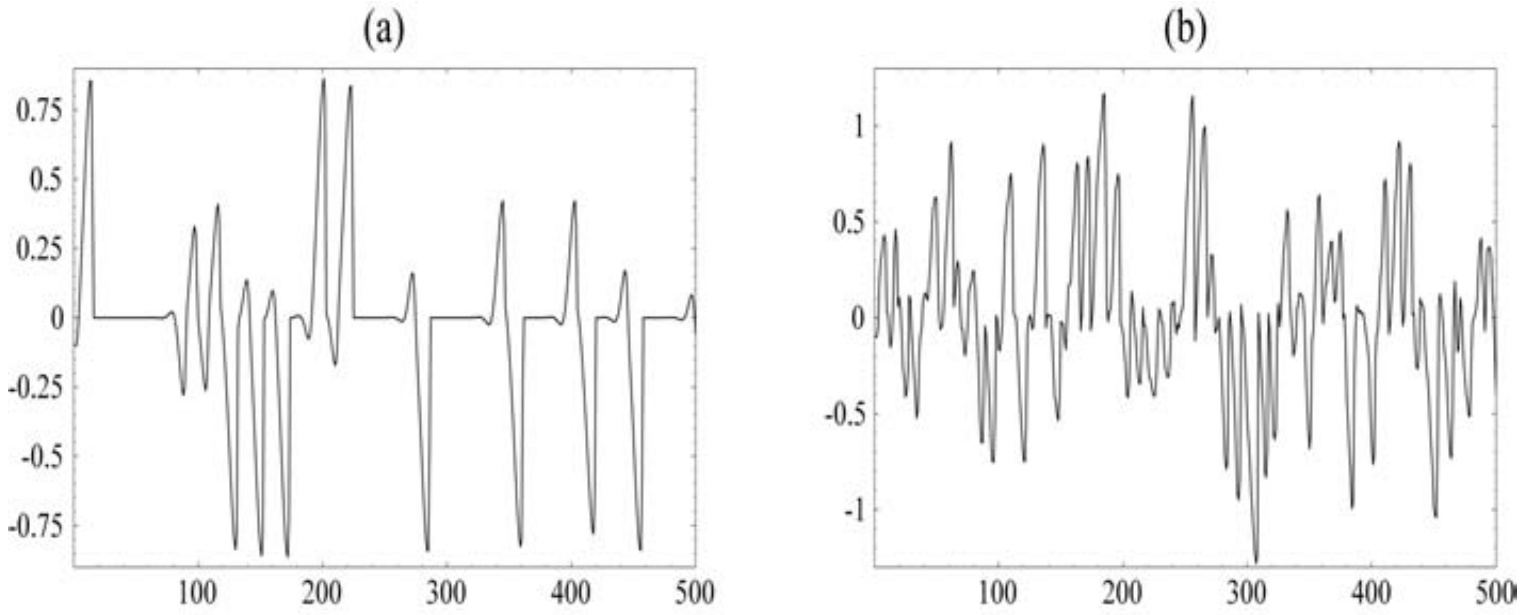
$$w_{i,t+1} = \frac{\exp\left(\beta U_{i,t}\right)}{\sum_{i=1}^{I}\exp\left(\beta U_{i,t}\right)}$$

Beauty of this model

- With very little fundamental risk one can get wild fluctuations *that are realistic* (for example almost not forecastable)

- Particular choices made silly (e.g. about utility function, beliefs, and even smartest agent is dumb), BUT the lessons learned are likely not to depend on these particular choices

Generated asset prices



Are economic environments like this?

- Economic agents are clearly influenced by nearby agents
- Economic agents are also influenced by common/aggregate factors
  - politicians/leaders
  - tax rules
  - wheather
  - market prices (at least in some markets)
- Economic agents do not passively wait and then respond
  - at least some are forward looking

Herb Simon's satisfying

- Even the smartest chess player only thinks a finite number of steps ahead
- Here I discuss an implementation of this idea based on Branch, Evans, & McGough (2010), BEM

1-period ahead optimizing

$$\begin{aligned} c_t^{-\gamma} &= \mathsf{E}_t\left[\beta c_{t+1}^{-\gamma}\left(\alpha z_{t+1} k_t^{\alpha-1} + 1 - \delta\right)\right] \\ c_t + k_t &= z_t k_{t-1}^{\alpha} + (1-\delta)\, k_{t-1} \end{aligned}$$

- Easy to solve for c_t if $c_{t+1} = c_{t+1}(k_t, z_{t+1})$ is known: just calculate conditional expectation given k_{t-1} and z_t

2-period ahead optimizing

- Suppose $c_{t+2} = c_{t+2}\left(k_{t+1}, z_{t+2}\right)$ is known
- Solve for $c_{t+1}(k_t, z_{t+1})$ by fitting an approximation on a grid
- Solve for c_t by calculating conditional expectation given k_{t-1} and z_t

N-period ahead optimizing

- Suppose $c_{t+N} = c_{t+N}\left(k_{t+N-1}, z_{t+N}\right)$ is known
- Straightforward to calculate c_t
  although it may take some calculations they are pretty straightforward
  no fixed point calculations as when calculating REE

N-period ahead optimizing

Big question: how to close the system?

- BEM: $c_{t+N}\left(k_{t+N-1}, z_{t+N}\right)$ is based on adaptive learning
- Alternatives:
  - $c_{t+N}\left(k_{t+N-1}, z_{t+N}\right) = c_{\text{steady state}}$
  - $c_{t+N}\left(k_{t+N-1}, z_{t+N}\right) =$ linearized policy rule

Some of my own views

- For policy analysis you will need at least some agents in the model that can think
  - $\Longrightarrow$ combination of smart and not so smart
- Until we have better models for individual behavior, we shouldn't take models that serious
  - useful to learn *lessons*, answer questions, structure ones thinking
- Lessons should seem robust to the "wilderness" of alternatives
- It is a strange that most models with "Keynesian" properties have sticky prices
  - are they really necessary?
  - news papers don't seem to think so

Sticky prices

- Keynesian story: demand by consumers $\downarrow \Longrightarrow$ demand for workers $\downarrow \Longrightarrow$ etc.
- Hard to get this without sticky prices, because as $Y \downarrow$ agents become desperate to work

My trick here

- Two markets:
  - nondurables: stable market
  - durables: less stable markets
  - workers fired in durable markets cannot switch (quickly)
  - uncertainty about employment prospects $\downarrow \Longrightarrow$ demand for durables $\downarrow$

Dealing with the wilderness

- Boundedly rational firms can be overoptimistic or overpessimistic about future
- Key lesson to be learned: Is it possible that rational firms will do as the boundedly rational firms?
  In most settings rational firms will do the opposite

Environment

- One period model
- Risk neutral firms (rational & mystic)
- Firms hire labor on a matching market
- Household supplies labor
- Production of nondurables is fixed (endowments)

Rational durable producers

Free entry determines vacancies and employment

$$\begin{aligned} \psi &= V^{(\phi-1)} v_r \left(PE\left[z\right] - W \right) \\ n_r &= V^{\phi-1} v_r \end{aligned}$$

- P : price of durable
- v_r : vacancies of rational firm
- V : aggregate amount of vacancies
- $V^{(\phi-1)}$: matching probability

Mystic producers

Mystic producers are identical except:

$$\widetilde{\mathsf{E}}\left[z\right] > \mathsf{E}\left[z\right] = 1.$$

or

$$\widetilde{\mathsf{E}}\left[z\right] < \mathsf{E}\left[z\right] = 1.$$

Individual household

- Two cases:
  1. full unemployment insurance
  2. no insurance

Individual household - full insurance

$$u'_x = Pu'_c$$

$$c + Px = e_w + WN$$

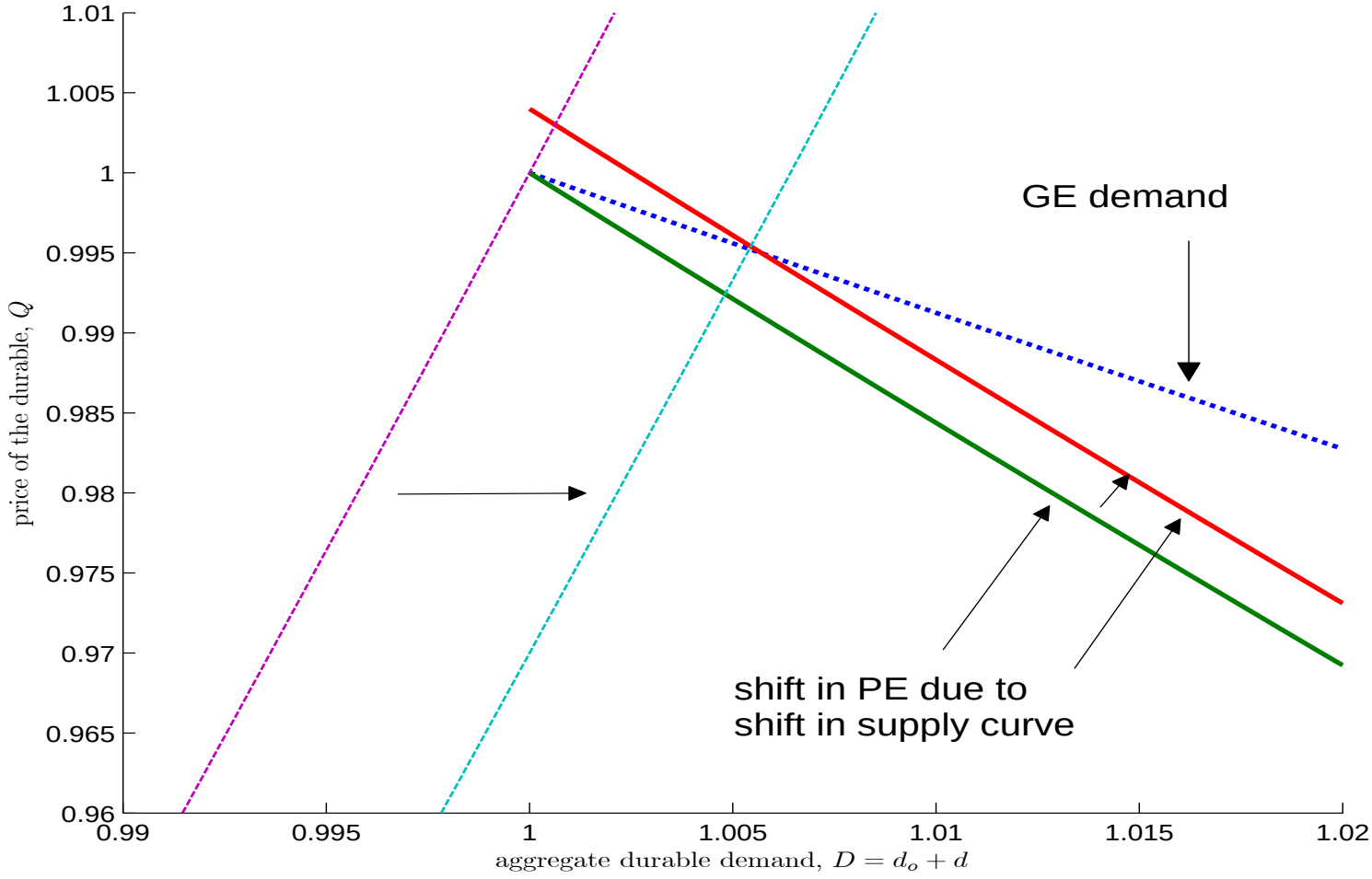
Individual household - no insurance

$$N \leq 1 \Longrightarrow \begin{cases} \text{probability of being unemployed} = 1 - N \\ \text{probability of being employed} = N \end{cases}$$

$$N > 1 \Longrightarrow \begin{cases} \text{probability of being unemployed} = 0 \\ \text{probability of being employed} = 1 \end{cases}$$

Individual household - no insurance

$$
\begin{aligned}
u'_x &= P\mathsf{E}\left[u'_c(c)\right] \\
&= P\begin{bmatrix} N & u'_c\left(e_w + (W - T) - Pd\right) \\ & + \\ (1-N) & u'_c\left(e_w + \mu - Pd\right) \end{bmatrix}
\end{aligned}
$$


1.01
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price of the durable, Q
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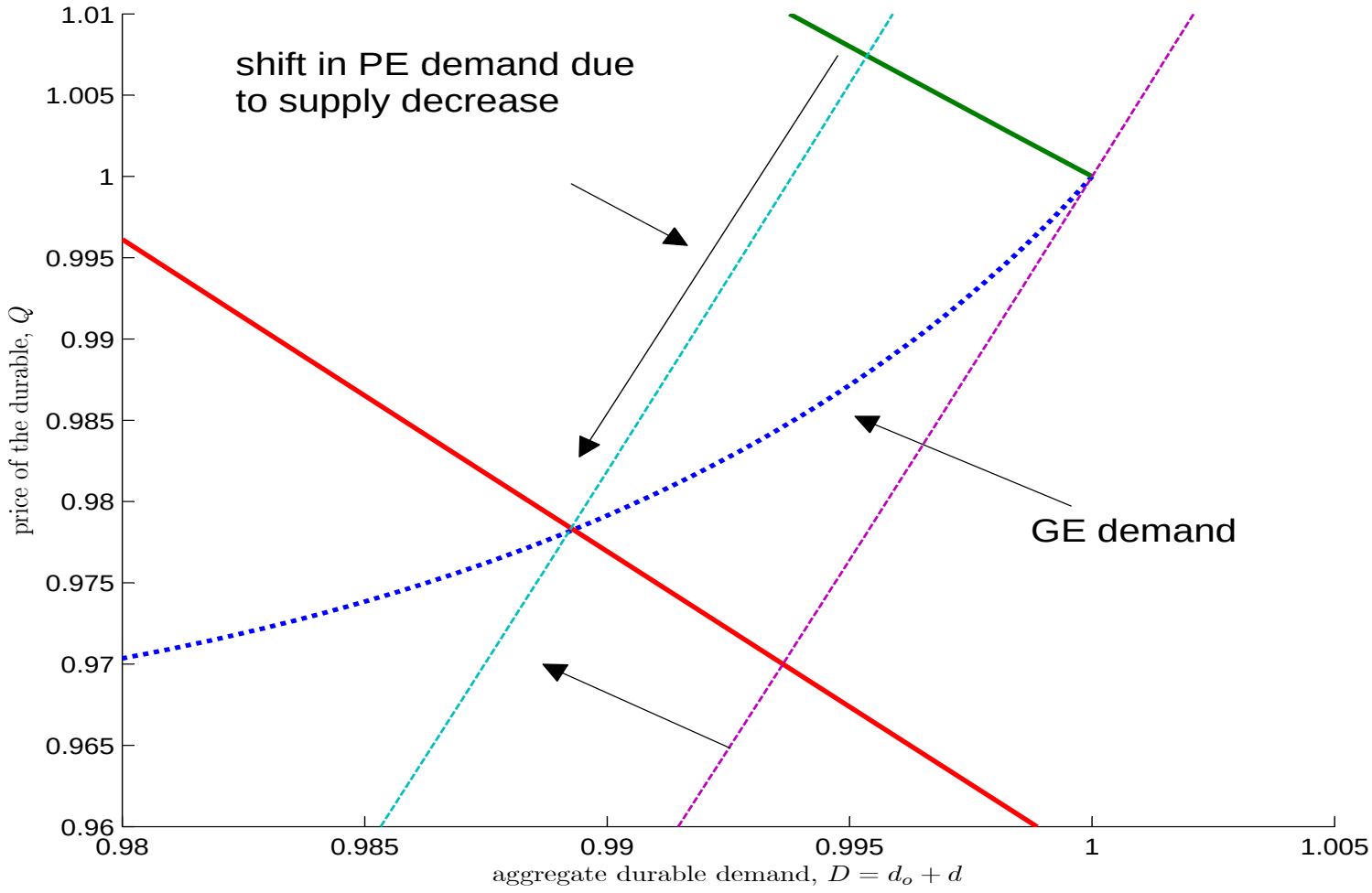
aggregate durable demand, $D = d_o + d$
GE demand
shift in PE due to
shift in supply curve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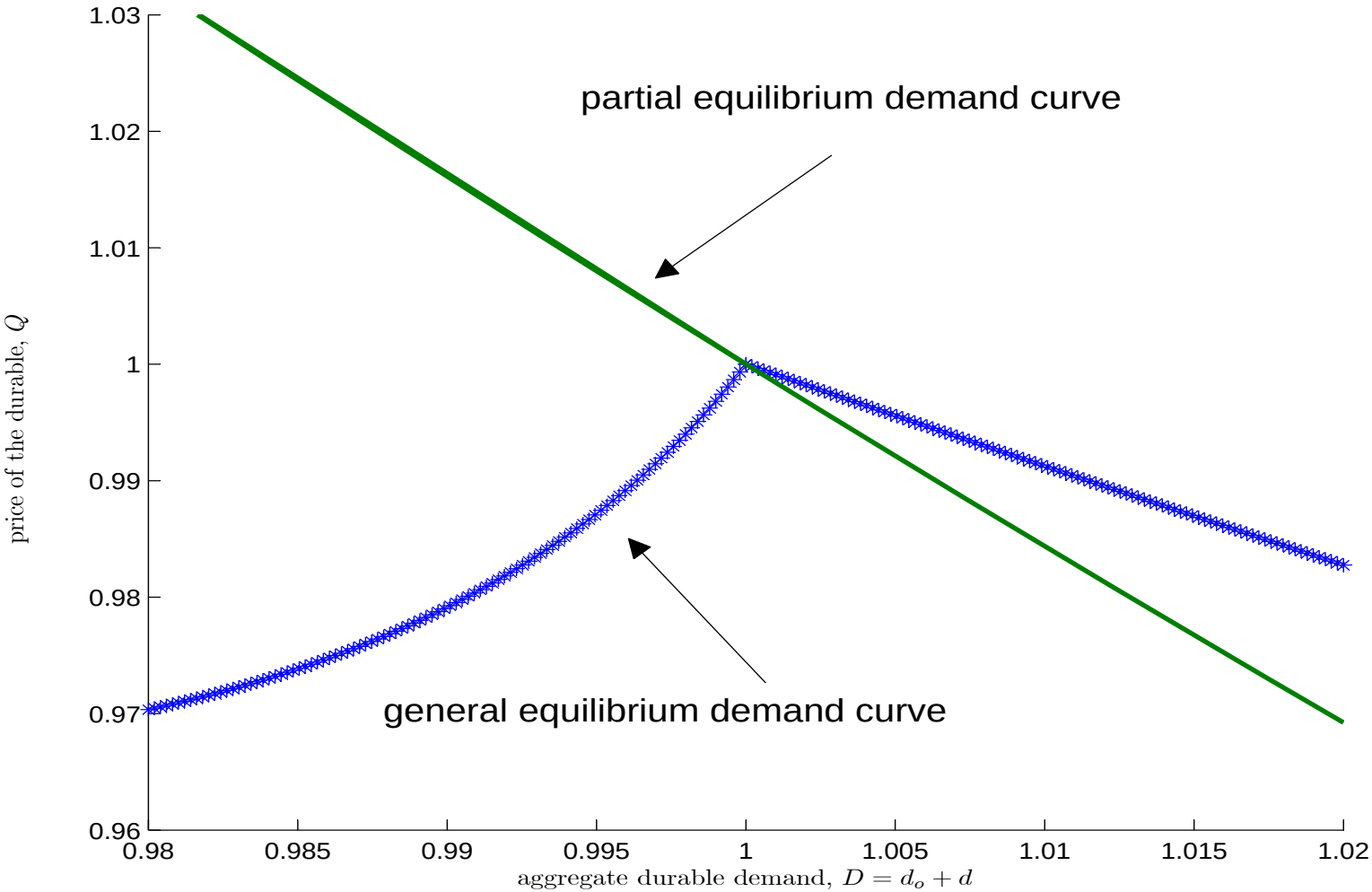
partial equilibrium demand curve
general equilibrium demand curve
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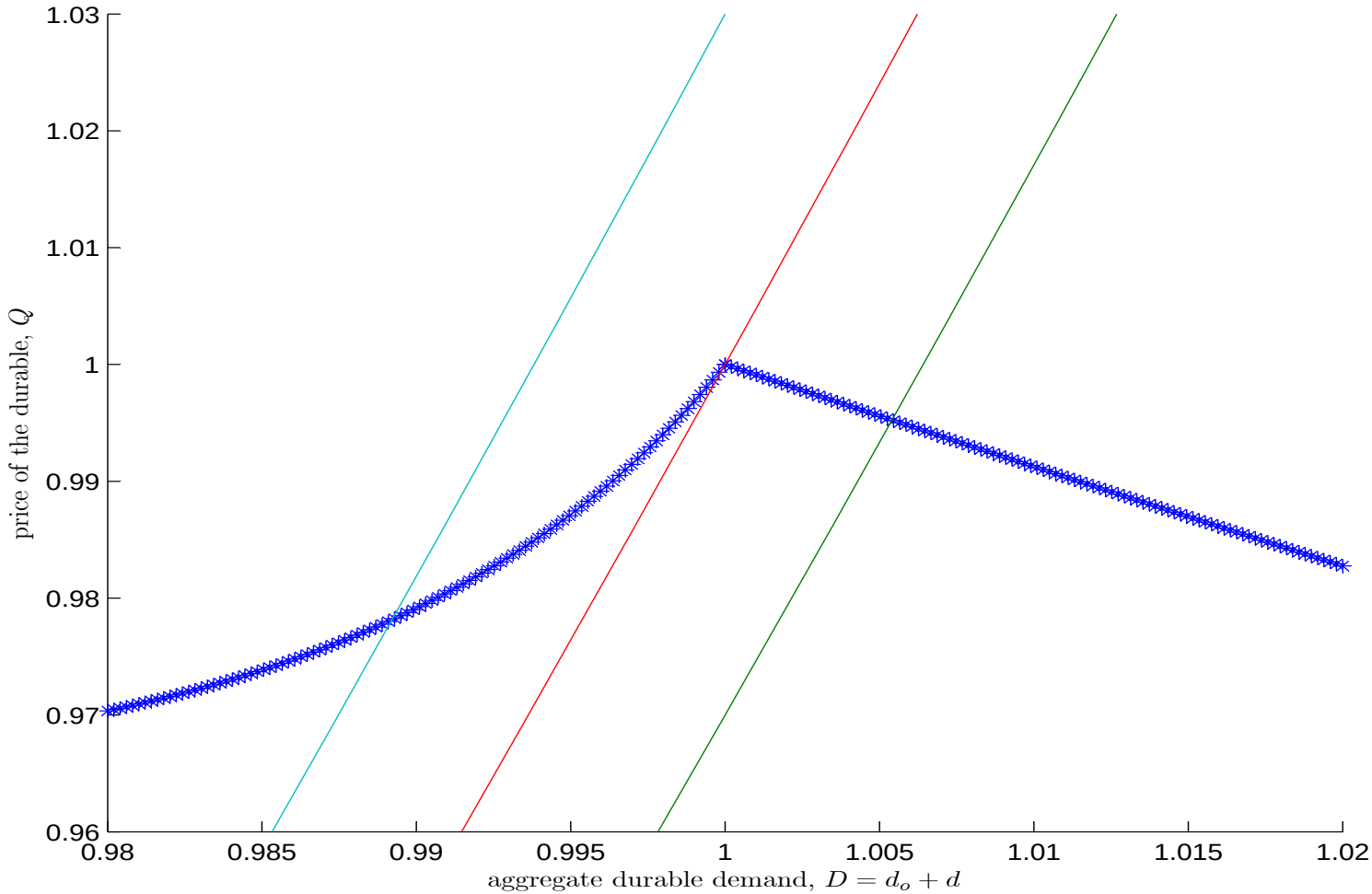
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