When Will the Fed Join the Third Millennium?

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Computation Matters: Tacoma Narrows, 1940

Tacoma Narrows bridge becomes unstable in the wind. Why? The engineers used linearization to analyze stability.

Computation Matters: Designing the Bomb

Fission is discovered

- Hahn and Strassman in Berlin observe neutron bombardment of uranium could produce barium – big surprise!
- February, 1939, Lise Meitner and Otto Frisch announce fission – uranium atoms splitting in half – and the enormous release of energy.
- Large effort on fission by physicists worldwide
- Everyone starts thinking about a bomb – the race is on!

The German effort

- Heisenberg directs German bomb project starting in April, 1942
- August 6, 1945, dinner at Farm Hall in England:
  - The use of an atomic bomb was announced to the "guests"
  - Heisenberg: "I don't believe a word of it"
  - Hahn: "I didn't think it would be possible for another twenty years"
  - Computations (~1941) showed that a bomb required tons of U-235.

The Japanese effort

- Dr. Yoshio Nishina Chaired Cmte. on Research in the Application of Nuclear Physics.
- A 1940 report concluded "it would probably be difficult even for the United States to realize the application of atomic power during the war" because of the large amount of U-235 needed for a bomb.

The American-British effort

- Einstein-Szilard letter (August 2,1939) to FDR warned of the possibility of atomic bombs and advocated research.
- My Hoover colleague Ed Teller helped write the letter and drove Szilard to Einstein's summer home.
- University of Birmingham, UK (1940):
  - Frisch-Peierls memorandum carefully computed the mean free path – distance between successive collisions – which said that a bomb needed only a few kilograms of U-235, light enough for a bomber.
  - They did not publish their results, giving the memo only to UK and US officials involved in weapons programs
- Manhattan Project begins in 1942
  - Develops two types of bombs - U-235 and Pu-239
  - You know the rest of the story
- We were the first to build the bomb because we did a better job at computation

Computation Matters: GPS and Desert Storm

- In an essay on Fama's Nobel Prize, John Cochrane praises the simplicity of Fama's theory:

  "[Efficient Markets] seems like a pretty simple 'theory,' hardly worth all the fuss. Perhaps you expect general relativity, lots of impenetrable equations."

- Facts:
  - The equations of GR are NOT impenetrable
  - GR is a critical part of the math behind GPS
  - GPS was a critical part of Desert Storm in 1991, saving thousands of coalition casualities
  - General McMaster credits GPS with helping at the Battle of 73 Easting - "the last great tank battle of the 20th century."
  - Einstein considered GR a simple theory

Everyone Uses High-Power Computing

Friends at my wife's church

Two personal acquaintances use modern computational tools to model complex biological problems

- Markus Covert, Cell (2010), described in NYT:

  "The simulation, ... on a cluster of 128 computers, models the complete life span of the cell at the molecular level, charting the interactions of 28 categories of molecules — including DNA, RNA, proteins and metabolites."

- John Stephens, President and CEO of HeartFlow (2018):

  "HeartFlow creates a personalized, digital 3D model of the arteries. Powerful computer algorithms solve millions of complex equations to assess .. blockages [of] blood flow. The result is a color-coded map that [shows], vessel-by-vessel, if sufficient blood is reaching the heart."

US: NOAA

- They are responsible for
  - Weather prediction
  - Modeling hurricanes
- They take this mandate seriously; spend $>$ \$25M per year on computers

US: National Stockpile Stewardship

- Problems:
  - We can't test nuclear weapons any more
  - Our bombs are old and may deteriorate with age
- Mandate: Use computational modeling so POTUS can be confident that hundreds of millions of people will be incinerated soon after he orders an attack.
  - Same activity in Russia and China
  - World agreed in 1990's this was better than nuclear tests
- What are the DOE's computational challenges?
  - "..confidence in nuclear weapons .. is based upon the verification ... of predictive simulation codes, ..., and the quantification of uncertainties associated with the simulations used to support the assessments."
  - "Verification ... is a scientific process to ascertain that a simulation is "right for the right reason"
  - ".. nuclear weapon simulations must extrapolate far beyond available data and must predict coupled, multi–scale physical phenomena that are difficult to isolate in experiments"
- Congress: "The Administrator for Nuclear Security shall develop and carry out a plan to develop exascale computing."

- They built Skybridge around 2010
- Predecessor of Skynet?

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- They recently built Sierra
  - Second fastest computer in the world (as of November, 2018)
  - Devoted to nuclear weapons work starting in 2019
  - Costs are in the hundreds of millions dollars

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High-Tech Finance

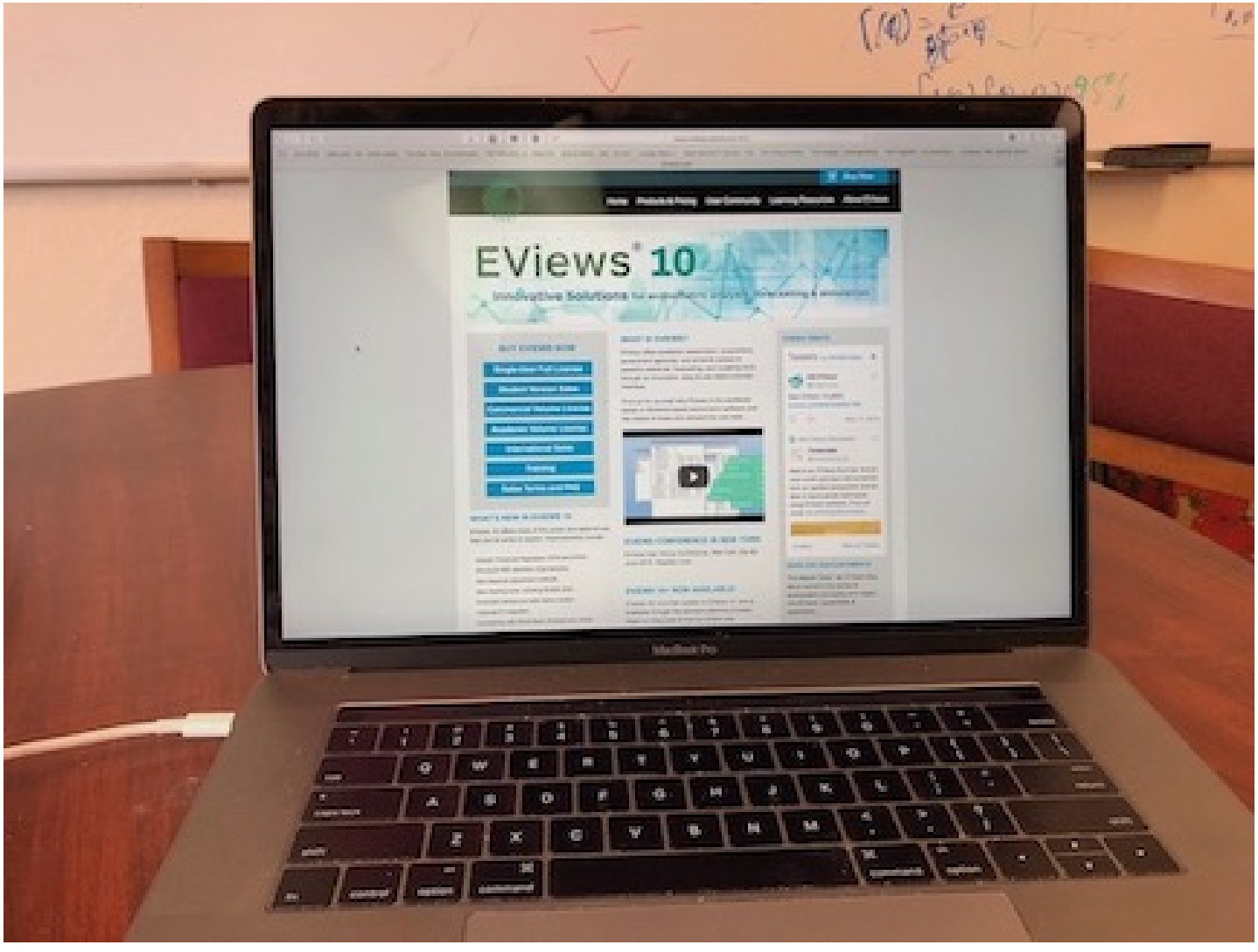
- Financial businesses are using modern computational methods and hardware
  - Option pricing
  - Financial product design
  - Data mining to learn credit-worthiness of borrowers
  - Generate information demanded by regulators
- Financial system complexity
  - Financial systems are complex, interconnected dynamical systems
  - Those interactions may lead to unstable financial markets even if all parties obey the rules
- Everybody wants a stable financial system
  - Borrowers want reliable access to credit markets
  - Lenders want to reduce risk exposure
  - Some may have benefited from a past financial collapse, but nobody wants a system where collapses will be common.

What is the Role of Government?

- Governments make financial markets possible
  - Contract law defines property rights
  - Courts enforce contract law
- Government regulators set the rules
  - Set capital requirements
  - Decides which assets they consider safe
- Government regulators rely on economic analyses
  - Rely somewhat on academic research
  - Regulators also do their own analyses
- Question: How do we analyze the economic impact of possible regulations of the hi-tech financial sector?
- Answer: "Mechanism Design", that is, choose the rules of the game so that the outcomes are good.

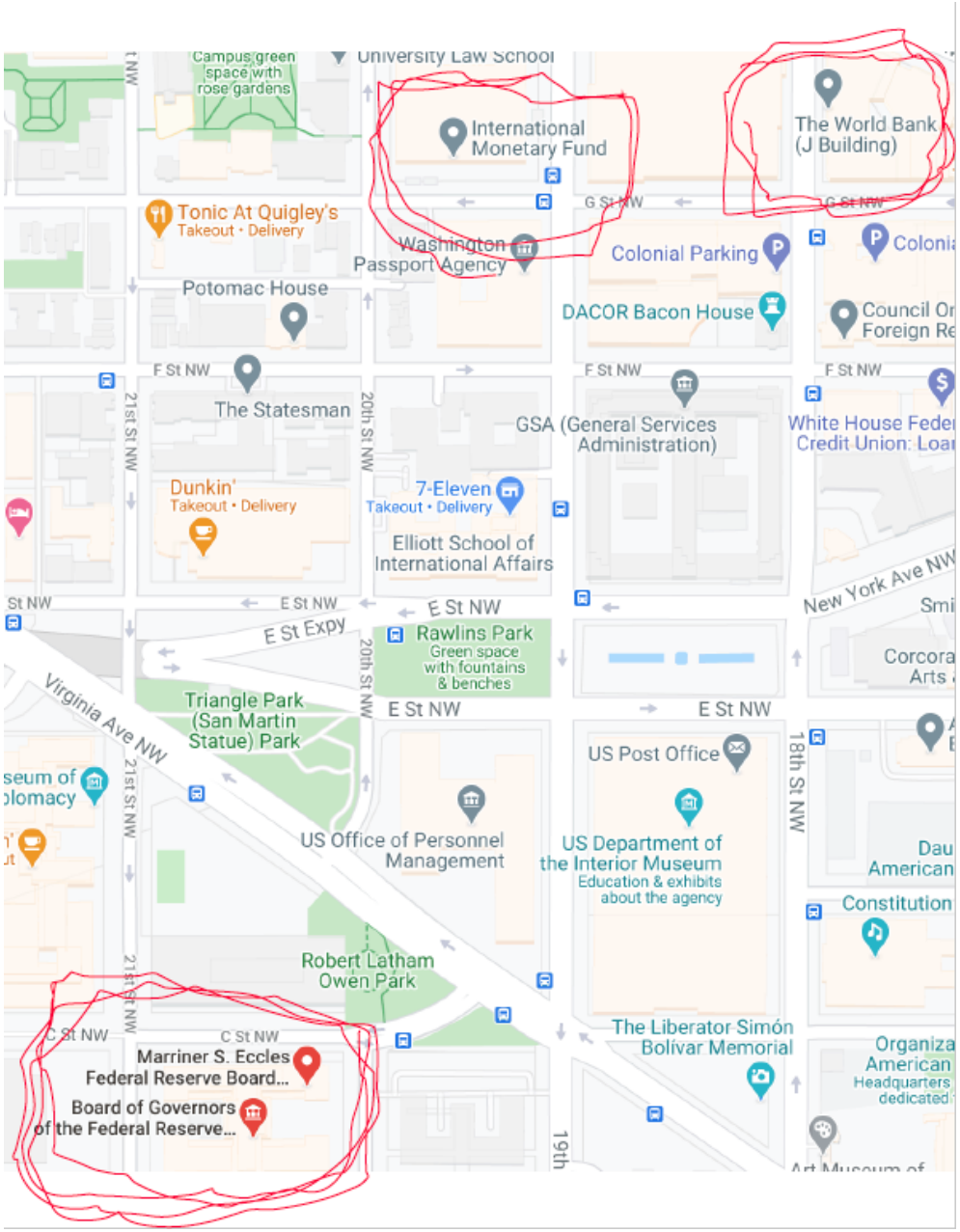
US Federal Reserve

- Mandate:
  - Price stability
  - Full employment
- Other responsibilities include
  - Lender of last resort
  - Regulation of financial institutions; regulate systemic risk
- My view is similar to that of DOE and Congress regarding nuclear weapons
  - ".. economic policy simulations must extrapolate far beyond available data and must predict coupled, multi–scale social and economic phenomena that are difficult to isolate in experiments"
  - The complexity of economic problems make them appropriate for exascale computing."
- What computational tools does the Fed use?


EViews 10

FRB/US uses Fed's code

- FRB/US is a hybrid dynamic macroeconomic model, part old-fashioned Keynesian, part ratex.
- Current version created in 1996.
- Wrote nonlinear equation solver and coded it in EViews
  - Why EViews? Because you could solve the problem and plot diagrams with the same software
  - What algorithm? 20-year old method
  - Who wrote code? A Fed guy (in-house)
- What did others use
  - World Bank: Birthplace of GAMS in the 1970's. Now commercial. Always has the state-of-the-art solvers. Used by Nordhaus in early 1990's!
  - IMF uses TROLL and other multi-sector, multi-country models
- Why write your own code when far better code is available, and used by many economists?


Campus green space with rose gardens
University Law School
International Monetary Fund
The World Bank (J Building)
Tonic At Quigley's
Takeout • Delivery
Washington Passport Agency
Colonial Parking
Potomac House
DACOR Bacon House
F St NW
The Statesman
GSA (General Services Administration)
21st St NW
20th St NW
Dunkin'
Takeout • Delivery
7-Eleven
Takeout • Delivery
Elliott School of International Affairs
E St NW
E St Expy
Rawlins Park
Green space with fountains & benches
Virginia Ave NW
Triangle Park (San Martin Statue) Park
US Post Office
US Office of Personnel Management
US Department of the Interior Museum
Education & exhibits about the agency
18th St NW
Constitution
Robert Latham Owen Park
C St NW
Marriner S. Eccles Federal Reserve Board...
Board of Governors of the Federal Reserve...
The Liberator Simón Bolívar Memorial
19th

Mismatch of Fed's ambitions and abilities

- The Federal Reserve wants to set the rules in the financial world.
- However, the Fed knows nothing about studying complex systems
  - Heartport speaks of solving millions of equations; the Fed calls a problem hard if it has hundreds of equations
  - Covert speaks of interactions among 28 different systems of a cell, many at different time scales; the Fed's models assume fewer interacting systems, acting at quarterly time steps
  - The Fed's models are done on laptops ... using EVIEWs
- Federal Reserve track record is not good
  - Before Great Recession, it deemed some derivatives as "safe"
  - Did not understand complexity
  - They were not safe

Can we Trust the Fed?

- Has a REAL job and SUBSTANTIAL resources
  - The Fed's job requires judgment on many dimensions
  - Not a job for nerds like me
- Training, software, and hardware
  - Many young people at the Fed want the training, software, and hardware that would help them do their research
  - Fed says "No."
  - The Fed has a sloppy attitude on doing its arithmetic
- Question: If the Fed cannot be bothered to be careful when doing arithmetic, why should we trust the Fed's choices on matters of judgment?

Policy Implication: Keep it Simple!

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- Federal Reserve regulations on assets
  - Before Great Recession, it deemed some derivatives as "safe"
  - Did not understand complexity
  - They were not safe
- Policy must be as simple and robust as possible
  - Only really safe assets should be certified "safe"

Economists CAN use high-power computing

Dynamic Stochastic Integration of Climate and Economy (DSICE)

- Includes uncertainty in both the future climate and economy
- Nine dimensions
  - Nordhaus' climate system, LRR productivity shocks, Tipping points
  - 600-year horizon
  - Time period: one year, results were the same down to two weeks.

Computational features

- Massive parallelism: one example used 80,000 cores for six hours
- 10% efficiency (which is good) and scalable up to 80,000 cores
- Verification – first time done in economics
- Uncertainty quantification (serious parameter sensitivity)

Solves difference equations in Banach spaces

- Describes most models is economics.
- Uses best methods for approximation, quadrature and optimization
- Easy to incorporate new methods

Recent paper of mine

- Cai, Judd-not-listed-as-author, and Lontzek (JPE, December, 2019)
- All software written in 2013

Our computer - NO SPECIAL ACCESS

Other Software Projects

- DPSOL, a general solver for DP problems
- Implement alternative assumptions on preferences
  - Risk-sensitive preferences
  - Robust decision making
  - Ambiguity
- Solve dynamic games
  - Supergame algorithm by Yeltekin-Cai-Judd
    - Find all Nash equilibria in games with states
    - Scalable up to 160,000 cores
    - Obvious candidate for asynchronous parallelization, and for exaflop machines
  - Compute all MPE in dynamic games

Other Software Projects

- DSGE models
  - Judd-Maliar-Maliar GSSA and EDS
    - Has been used on simple models with ~200 dimensions on a desktop
    - Clearly parallelizable
    - Widely applicable
  - Perturbation methods
  - NLCEQ, SCEQ methods
    - Dominates log-linearization since it is a global method
    - Parallelizable
- Solving polynomials
  - Homotopy methods for polynomials
  - Groebner bases for polynomial equations
- Applications
  - Dynamic tax policy (with Yeltekin, Mueller)
    - Barro's random walk theory is wrong
    - Sargent's 2002 JPE paper is a computational atrocity
  - Optimal life cycle tax policy with borrowing costs and constraints (with Rangel, Mueller)
  - Computing likelihood level sets (with Reich)
  - Solving for time consistent solutions

Economists are far behind

- Opinion of an OR person who knows economists well: “Economists are so far behind that soon they will not be able to catch up”
- (By the way, she and I are not acquainted.)
- WHY?

Economists's Views on Computation and Modeling

Nordhaus on Models and Computation

Nordhaus (President of AEA, Provost of Yale)

- "*We need to recognize that most economists and environmental scientists are amateurs at software design and architecture*."
  - Response: I agree. In DICE2010, Nordhaus assumed that CO2 emitted 10 years from now would cause warming...NOW.
- "*We should restrain the urge to develop ever larger and more complex computational models unless there is a clear case that they will improve our understanding*."
  - Response: How can we know which models will be useful before we solve them?
- "*We need also to ask, do we fully understand the implications of our assumptions?*'
  - Response: Computation is the third leg of science because it can help us understand our assumptions.

- "*Scientists and policy makers often emphasize supercomputing as the "frontier" aspect of computation, the "grand challenges of computation," or the need for "high performance computing." These are the romantic moon shots of the computer age.*"
  - I prefer the old moon shot days:
    - JFK: "We go to the moon in this decade not because it is easy, but because it is hard"
- "*The large systems are clearly not as versatile as personal computers.*"
  - Yes, no email, facebook, instagram, iTunes, youtube, porn...

Nordhaus and Wieland on Costs

- Nordhaus on supercomputer costs
  - *"The price of supercomputing is ... unfavorable relative to personal computers. IBM's ... Blue Horizon ... had a list price in 2002 of ... about $30,000 per Gflop ...approximately 34 times as expensive ... as a Dell personal computer in 2004."*
- Wieland on software costs
  - Approves use of Matlab.
  - Says TROLL is better in many ways but is too expensive
- My Response: It would have taken us centuries to do what we have done with DSICE if we used a PC. If we use an appropriate discount rate, getting the right answers in the next century has PV of zero.
- Using supercomputers and advanced software expands what is *possible!* The question is *not* cost, but rather the benefits justify the cost. Apparently Nordhaus and Wieland do not think that the benefits of more serious computational analysis in economics is not worth the cost.

One economist's opinion

2014 presentation of a Columbia University macroeconomist:

- He started by saying macro models are very difficult to solve
  - He flew from NYC to SFO
  - Fact: The equations used to design his airplane were far more complex than any macro model
- He used a linearization procedure and was happy he found unit roots.
  - Fact: If a linearization produces unit roots, you know nothing about the stability of the system
  - I referred him to papers by Benahbib in the late 1970's
- I asked him what he is doing so that his students can solve models he cannot
  - "I would tell them to visit Benhabib (at NYU)"
  - Typical Ivy League behavior: send students to "lesser" universities to learn serious math.

Richard Clarida is now Fed Vice-Chairman

- In January, 2021, I asked him what he is doing to help Fed economists solve complex models
- He said "We should take this offline"

Typical (Official?) Macro View: V. V. Chari

- Testified at a 2010 Congressional hearing on DSGE models
- A models is an:
  - *".. abstraction which incorporates features of the real world thought important to answer the policy question ... and leaves out details unlikely to affect the answer much."*
  - Question: How do you know, before you do the analysis, which details are not important? do you have "perfect foresight"? If so, then you knew I would ask that question but you make no response.

- Chari: *"Abstracting from irrelevant detail is essential given scarce computational resources,.."*
- Economics was not constrained by computational resources, even in 2010
  - Cai and Judd were using high-power computing in Cai's 2008 thesis
  - I have used millions of core hours in the past several years. How much have you used? macroeconomists in general?
  - Fact: Work by Cai, Judd, Brumm, Scheidegger, Yeltekin, Rangel, Mueller, Reich,... used supercomputers – is NOT constrained by scarce computational resources.

- Chari: *"...not to mention the limits of the human mind in absorbing detail!"*
- Oh, where do I begin?
  - I asked him "Which minds are you describing?" Others exclude me from the set of mentally deficient economists, but not Chari.
  - Fact: Work by Cai, Judd, L. Maliar, S. Maliar, Brumm, Scheidegger, Kubler, Hazonhodjic, Kotlikoff, Yeltekin, Rangel, Mueller, Schmedders, Reich,... show that economics is NOT constrained by limits of the human mind.
  - Perhaps macro should encourage people with better minds to become economists.

William Jennings Bryan

In his July 9, 1896 speech, one of the most famous speeches in US political history, he addressed the advocates of the gold standard:

> *"You shall not crucify mankind upon a cross of gold."*

Suppose he were here today

- Glad that the gold standard is gone; but
- What would he say about monetary and financial policy analysis at the Fed . . . in the third millennium. . . being based on laptops . . . with minuscule computing power . . . using obsolete, homemade code?