PENN WHARTON
UNIVERSITY *of* PENNSYLVANIA
Budget Model

MATLAB Computational Finance Conference 2019, New York

Penn Wharton Budget Model

Macroeconomics in MATLAB

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What is the Penn Wharton Budget Model?

Mission: “PWBM is a nonpartisan, research-based initiative that provides accurate, accessible and transparent economic analysis of public policy’s fiscal impact…”

We project long-run macroeconomic effects of policy similar to work by the Congressional Budget Office and the Joint Committee on Taxation.

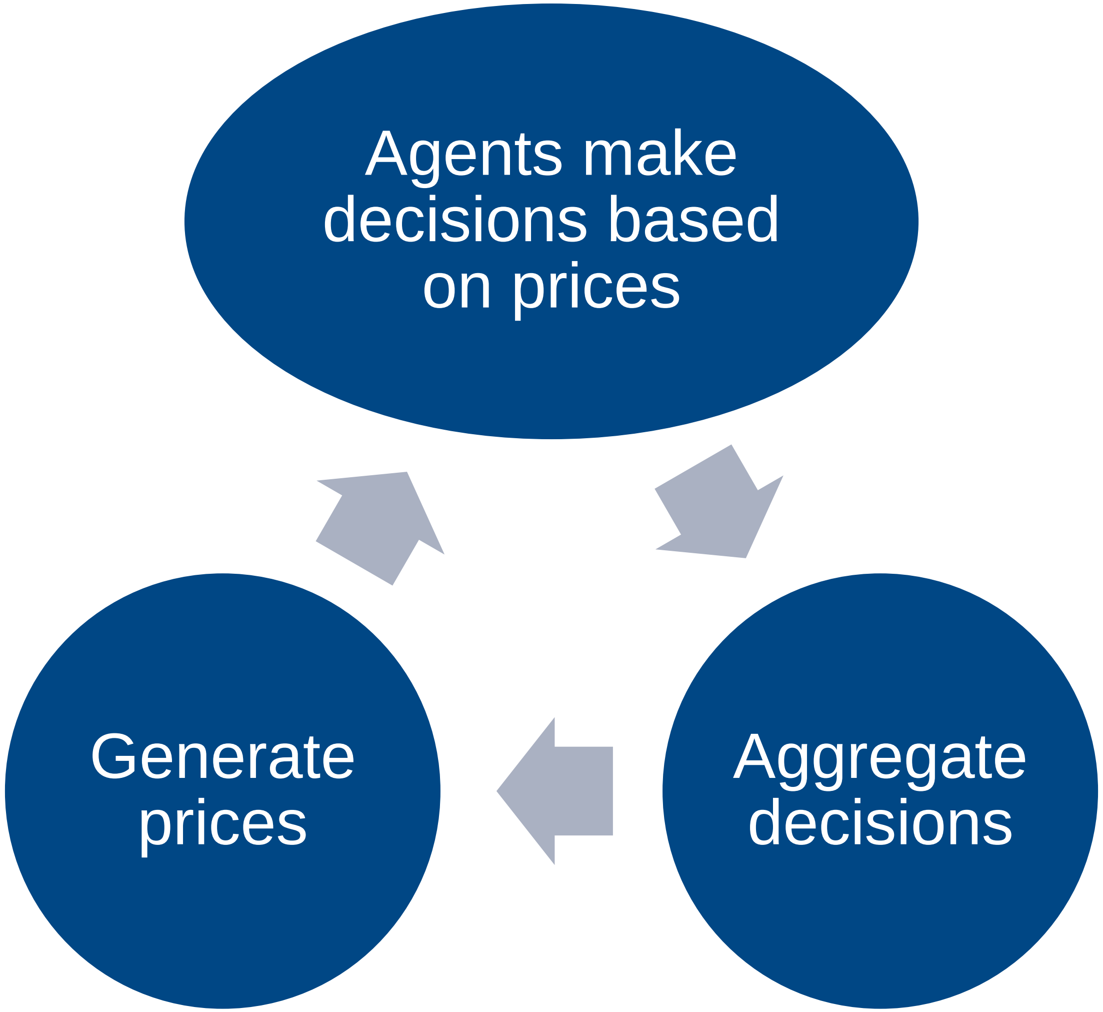
PWBM works with U.S. Congress, Executive Branch, think tanks, and others.

Frequently cited in major media: New York Times, Wall St Journal, Bloomberg, Washington Post, and more.

Parts of the Penn Wharton Model

- Demographic Microsimulation:
  - Monte Carlo projections of individuals through time.
  - Variables on income, family, education, race, immigration, disability, mortality, etc.
  - Transitions calibrated from historical micro-data.
- Policy Modules:
  - Personal income tax
  - Business tax
  - Social Security (OASI)
- Dynamic Overlapping Generations Equilibrium Model

Dynamic Model: General Equilibrium



Advantages:

- Accounts for forward looking, behavioral responses.
- Feedback: Micro to macro.
- “Structural” approach vs. “reduced form.” Modeling at agent-level can better predict responses to policies not seen historically – in contrast to statistical approaches (*e.g.*, regressions, ML).

Agents in the Dynamic Model

Who are decision makers?

- Heterogeneous households:
  - Adults: Working age and retired
  - Birth year, age, wealth level, productivity level (stochastic with persistence), lifetime earnings, immigration status. (Adding more)
- Firms: Competitive, profit maximizing, corporate & pass-through
- Foreign investors: Arbitrageurs

Household's problem

Rational expectations, perfect foresight.

Decide: How much to work and how much to save/consume.

Prices:

- Wage = Market wage level × HH's idiosyncratic productivity shock.
- Asset returns: Capital return and gov't debt return. (No endogenous portfolio choice).

Household problem (cont.)

Bewley-type model, constrained optimization, Bellman equation:

$$V(\boldsymbol{s};\boldsymbol{S}) = \max_{c,n} u(c,n) + \gamma\beta E[V(\mathbf{s}';\boldsymbol{S}')]$$

subject to

$$c + (a' - a) = wzn + ra - \tau(\boldsymbol{s},n,a') + ss(\boldsymbol{s}) + beq$$

where $u()$ is HH period utility, $V()$ = value function,

c = consumption, ***s*** *= HH state,* ***S*** *= aggregate state,*

w = wage level, z = HH productivity shock, n = labor supply,

a = assets, r = return on assets, $\tau()$ *= tax liability,* $ss()$ *= OASI benefits,*

beq = bequests received, γ *= survival probability,* β *= time discount*

Solve backwards

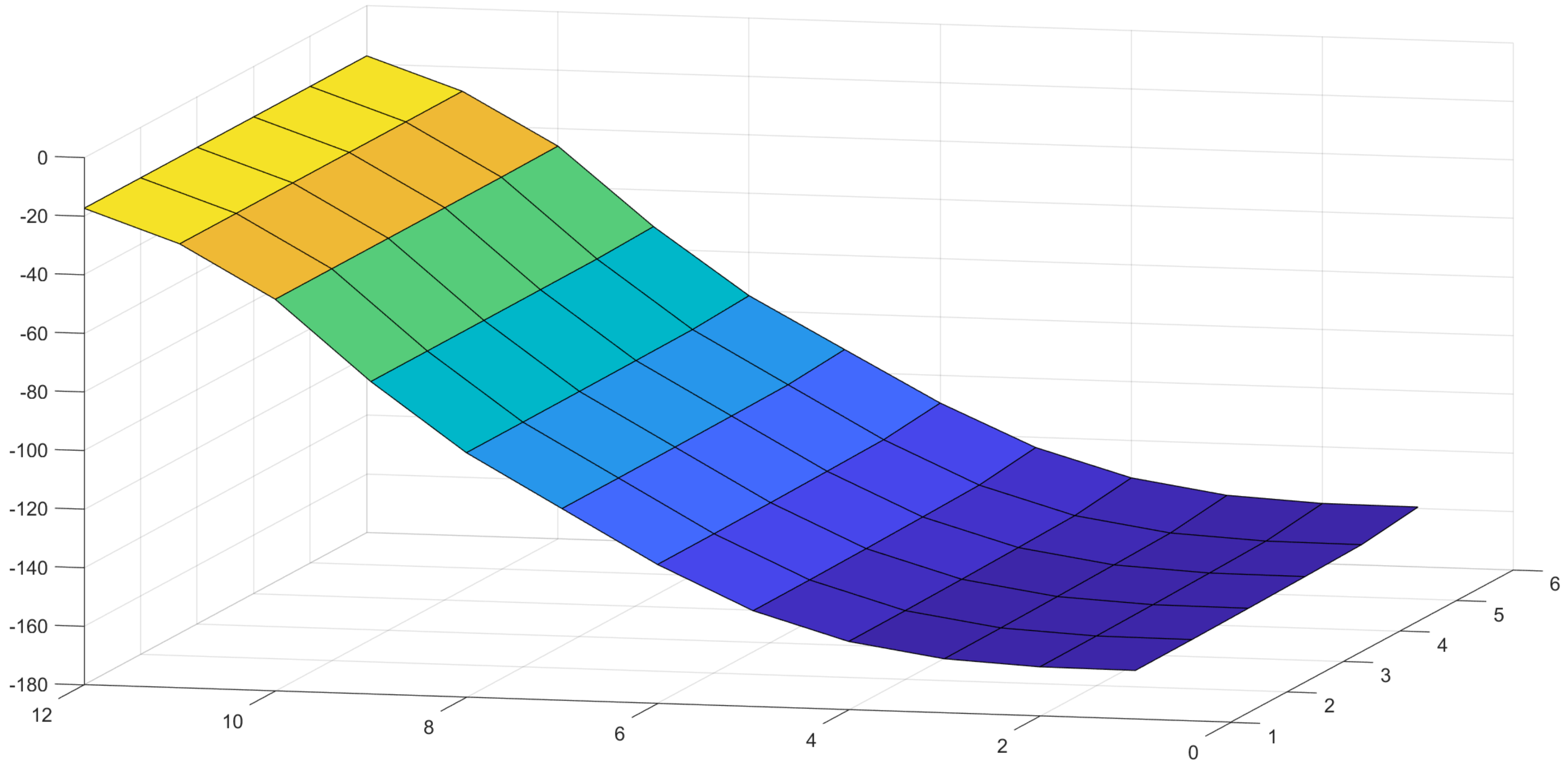
We don’t know shape of value function. Numerically approximate.

- Take *V(s;S)* *as a given function.*
- Solve for *V(s;S)*
- Take *V(s’;S’)* *as a given function.*

Grid method: Solve at discrete points in **s**-space. Interpolate. Iterate to convergence.
Parallelize grid computation. We separate by cohort.

Slow in native MATLAB. We use C code generation → MEX
Example: 3.5 mins with MEX vs. 6.5 hrs

Value function for native-born 24 year-old, productivity level 3



Optimal decisions

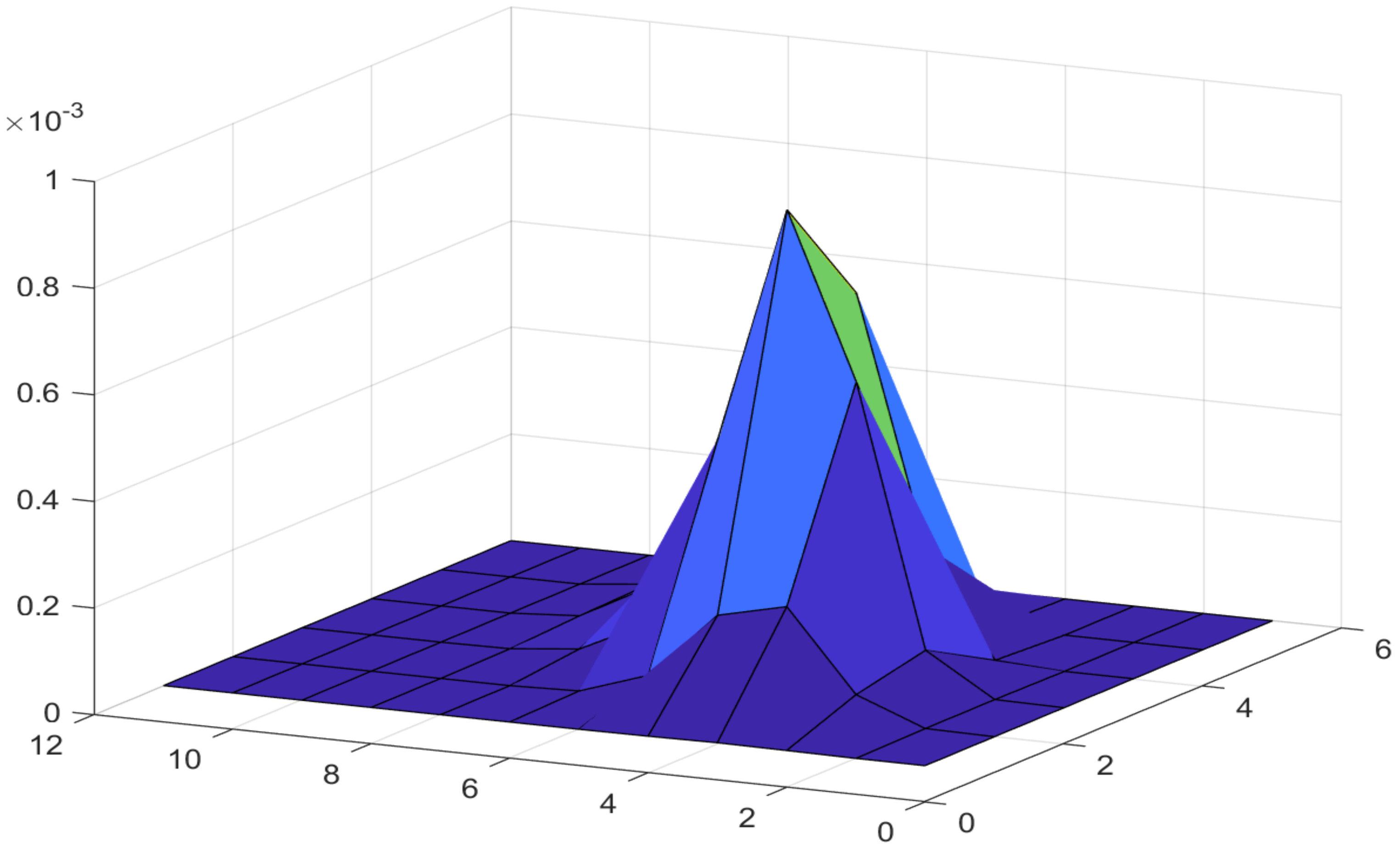
Each household's optimal decision adds to aggregate

- Savings → capital and gov't debt
- Labor

Transition the household to a new state:

- Deterministic transition: Age
- Stochastic transition: Productivity shock
- Choice transition: Wealth, lifetime earnings

Distribution of native-born 61 year-olds, productivity level 4



Aggregation

Total assets:

$$A = \int a^*(\boldsymbol{s}; \boldsymbol{S}) d\boldsymbol{s}$$

Total effective labor:

$$L = \int z(\boldsymbol{s}) n^*(\boldsymbol{s}; \boldsymbol{S}) d\boldsymbol{s}$$

Aggregates → Market-clearing prices (by iterated convergence).

PWBM Economic Projection

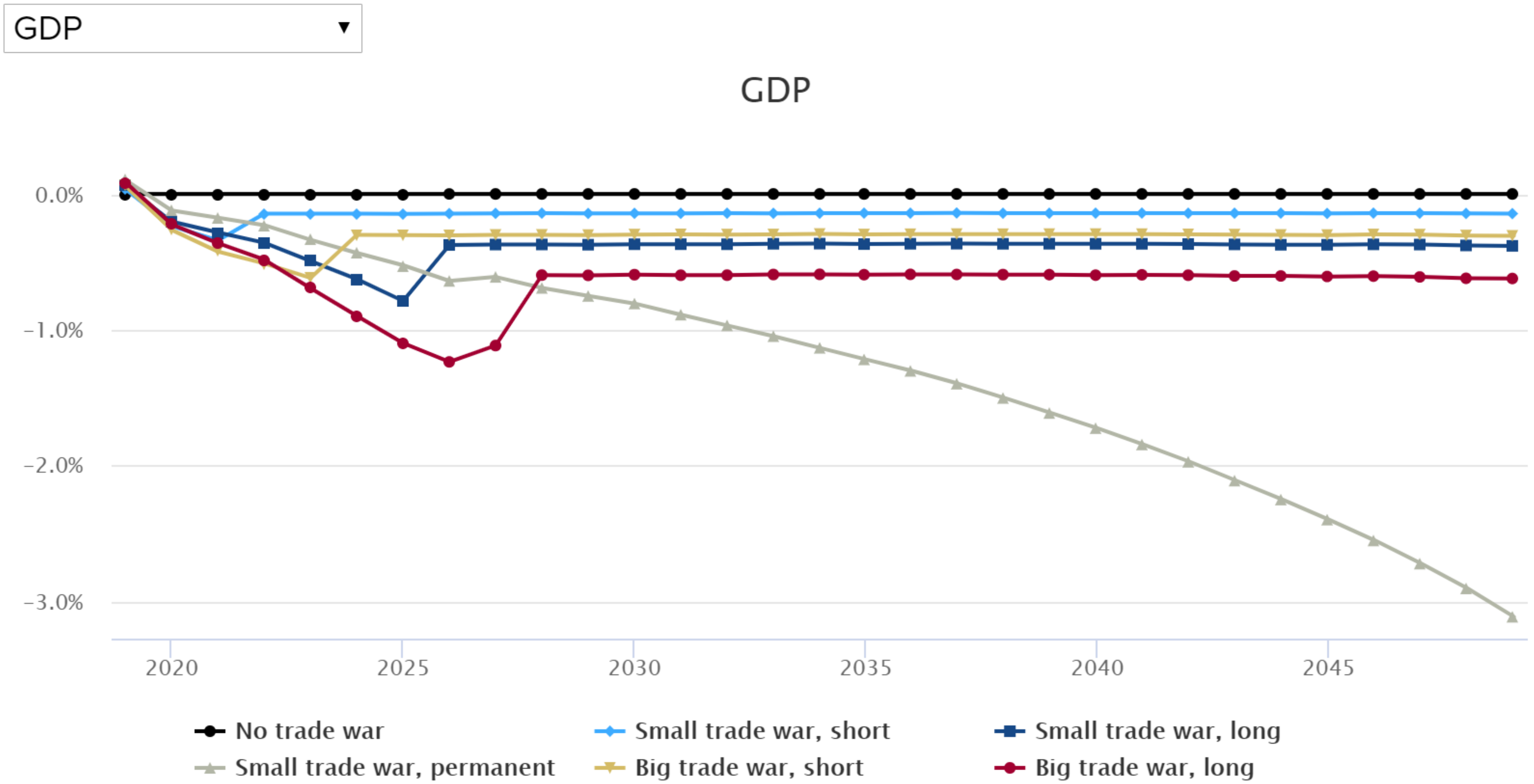
Model captures behavioral and general equilibrium price effects.

But calibrating model to levels is challenging.

Usually, PWBM produces results from the micro-simulation with an overlay of the dynamic effects. This captures levels and detail while accounting for dynamic effects.

Other times, we show policy results as deviations from baseline.

Example: GDP in Trade War (Deviations from No Trade War)



Main Computational Challenge

Solving agent's optimization problem for each agent state without knowing the continuation value function.

This computational constraint restricts the size of the grid (both in number of dimensions and refinement of each dimension).

<u>Approaches</u>

- Massive parallelism: GPU computing
- Adaptive grid, interpolative, other numerical methods to approximate value function.
- Machine learning

Thank you.

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