Penn Wharton Budget Model: Overview

www.budgetmodel.wharton.upenn.edu

June 1, 2016
Combines modern advances of theoretical modeling, big data, Agile testing and development, cloud computing and dynamic visualization to solve challenging government budget questions:

- **Model**: Micro-simulation model that allows for a rich amount of heterogeneity and transitions
- **Data**: A new data store combining large data sets at the household and aggregate level, used for model calibration
- **Agile testing**: Model validation against history, at household and aggregate level (“functional” testing) and “unit” tests
- **Cloud Computing**: Thousands of processors solving the economy across the entire set of policy combinations (e.g., for Social Security, 4,096 different policy combinations). Results stored on load-balanced JSON servers for immediate access.
- **Visualization**: Dynamic display reflects user choices
Main Elements of the Model

The static model has three major components:

1. **The Core Module**: A micro-simulation (PPISIM) that tracks the U.S. population by salient subgroups identified by a set of attributes such as age, gender, race, family structure and size, marital status, education, labor force status, disability, earnings, etc.)

2. **Production Sector**: An aggregate production function relating output (GDP) to capital and efficiency-indexed labor.¹

3. **Policy Modules**: Federal policies evaluated on a static basis

¹Policies influence GDP growth by affecting the growth of capital and labor inputs, including changes in the composition of workers, for example, through immigration reforms. Another document describes the dynamic version of our model which calculates how individuals alter their saving and labor supply decisions, to influence the aggregate capital stock and labor.
1. Core Module
General Strategy

1. Start with **population subgroups** = \{Dual-Headed Male, Dual-Headed Female, Single-Headed Male, Single-Headed Female, Non-family Male, Non-family Female, Kids of Dual Headed, Kids of Single Headed, Male and Female Orphans\} \times \text{race} = \{White, Black, Hispanic, Asian, Other\}^2

2. Estimate and assign each subgroup \times race relevant **attributes** = \{fertility, mortality, immigration, labor-force status, education, marriage, divorce, capital, disability, earnings\}

3. Evolve subgroup \times race with Markov **transitions**. Build **special micro-sims** where important (e.g., marriage).

4. Check performance against historical Census data

5. **Project forward** beyond 2015

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For some interactions, data samples are too small to be reliable. For example, orphans are not decomposed by all races.
Main Data Sets

The model is calibrated using several micro-level and aggregate data sets. A partial list includes:

- Current Population Survey (Cross-Sections & Longitudinal)
- Census Population Projections
- Panel Study on Income Dynamics
- Survey of Consumer Finances
- IRS Statistics of Income
- SSA Benefits Public Use File
- SSA Earnings Public Use File
- Bureau of Economic Analysis (Macro)
- Bureau of Labor Statistics (Macro)
- National Longitudinal Surveys
- CDC Vital Statistics
- National Hospital Care Survey
In year $t$, the incidence of \textbf{fertility} for females ages 14-49 is $f_t(age, \text{race, education})$.

\textbf{Mortality} is governed by the probability of dying $d$ in year $t$: $d_t(age, gender, race)$.

\textbf{Immigrants} enter the population $P$ in year $t$ at rate $\lambda_t$: $\lambda_t P_t$.

\textbf{Labor Force Status} for a person in population subgroup $i$ at time $t$, $LFS_{i,t}$, is given by a Markov transition function: $F_t(LFS_{i,t} | LFS_{i,t-1}, gender_i, age_{i,t}, education_{i,t-1})$

where $F_t$ is the probability that state $LFS_{i,t}$ is reached in year $t$.

\footnote{PPISIM tracks legal and undocumented immigrants separately.}
The **education status** for a person in population subgroup \(i\) at time \(t\):

\[
E_t(e_{i,t}|e_{i,t-1}, age_{i,t-1}, gender_{i}, race_{i})
\]

**Marriage** requires more micro-foundations. Single females ages 18-84 meet single males ages 18-84 multiple (\(N\)) times per year, half randomly drawn from female’s own racial group. A marriage is not guaranteed: The female decides whether to marry with probability \(P\). If no marriage, male and female meet more singles. The acceptance rate (\(acc\)) depends on (\(race, education, age\)) of the male (\(m\)) and female (\(f\)):

\[
mar(race_f, edu_f, age_f) =
\]

\[
N \times \sum_{race_m, edu_m, age_m} [P(race_m, edu_m, age_m|race_f) \times
\]

\[
acc(race_f, edu_f, age_f, race_m, edu_m, age_m)]
\]
The **divorce** probability depends on race, education and age of wife \((f)\):

\[
\text{div}(\text{race}_f, \text{edu}_f, \text{age}_f)
\]

**Capital** assigned to person \(i\) at time \(t\), \(k_{i,t}\), includes private, public and foreign sources. Simple Markov \(K\) process assumes per-value values grow with productivity.

\[
K_t(k_{i,t} \mid k_{i,t-1}, \text{age}_{i,t-1}, \text{gender}_i, \text{race}_i, \text{edu}_{i,t-1})
\]

**Disability** status \(\delta\) is governed by Markov process \(D\):

\[
D_t(\delta_{i,t} \mid \delta_{i,t-1}, \text{age}_{i,t-1}, \text{gender}_i, \text{race}_i)
\]
Log **labor earnings** of individual $i$ in period $t$, $Z_{i,t}$, conditioned on all of the person’s attributes $X_{j,i,t}$ (race, age, gender, marital status, family size, disability status, labor force status, education, and interactions of all of these attributes).

- Only full- and part-time workers have positive earnings.
- Regression includes a first-order auto-regressive effect of past earnings.
- The parameters $\theta$ capture the influence of individual attributes and the parameter $\alpha$ captures the economy’s capital stock that workers use.

$$lnZ_{i,t} = ln(1 - \alpha) + (1 - \alpha) \sum_{j=1}^{k} \theta_j X_{j,i,t} + u_{i,t}$$
Various Calibration Summaries

Fertility

Fertility Per 1,000 Women in the United States

- 2000
- 2010
- 2020
- 2030
- 2040
Various Calibration Summaries
Deaths per 100,000 People

White Females

Deaths per 100,000 People

Age

1995 2005 2015

White Males

Deaths per 100,000 People

Age

1995 2005 2015

Black Females

Deaths per 100,000 People

Age

1995 2005 2015

Black Males

Deaths per 100,000 People

Age

1995 2005 2015
Various Calibration Summaries
Deaths per 100,000 People

Hispanic Females

Hispanic Males

Deaths per 100,000 People

Age
Various Calibration Summaries
Aggregate Mortality Rates (including some projected)

U.S. Mortality Rates By Age: Historical and Simulation Benchmark Projection
Various Calibration Summaries
Population Distributions by Family Type

Population Distributions by Family Type - 1995
- Dual Headed Male
- Dual Headed Female
- Single Headed Male
- Single Headed Female
- Nonfamily Male
- Nonfamily Female
- Kids of Dual Headed
- Kids of Single Headed
- Unrelated Male Orphans
- Unrelated Female Orphans
- Total

Population Distributions by Family Type - 2013
- Dual Headed Male
- Dual Headed Female
- Single Headed Male
- Single Headed Female
- Nonfamily Male
- Nonfamily Female
- Kids of Dual Headed
- Kids of Single Headed
- Unrelated Male Orphans
- Unrelated Female Orphans
- Total

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Various Calibration Summaries

Immigration

U.S. Immigrants -- Simulation Benchmark Distribution by Age Group

- Female
- Male
Various Calibration Summaries

Immigration

Legal Immigration as a Share of the U.S. Population

Undocumented Immigration as a Share of the U.S. Population
## Various Calibration Summaries
### Labor Force Transitions

| Age Range | Gender: | Females | | | | Males | | | | | | | LFS in Period $t+1$ |
|-----------|---------|---------|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|           | LF Status | NW | PT | FT | NW | PT | FT | NW | PT | FT | NW | PT | FT | NW | PT | FT |
| 18-29     | NW       | 59.0 | 32.7 | 8.3 | 57.9 | 31.6 | 10.5 |   |   |   |   |   |   |   |   |   |
|           | PT       | 17.9 | 60.4 | 21.8 | 16.3 | 56.1 | 27.6 |   |   |   |   |   |   |   |   |   |
|           | FT       | 6.3  | 21.3 | 72.4 | 4.8  | 17.0 | 78.3 |   |   |   |   |   |   |   |   |   |
| 30-44     | NW       | 76.6 | 14.1 | 9.4 | 76.1 | 13.2 | 10.7 |   |   |   |   |   |   |   |   |   |
|           | PT       | 15.5 | 48.4 | 36.1 | 15.3 | 44.2 | 40.5 |   |   |   |   |   |   |   |   |   |
|           | FT       | 3.5  | 11.7 | 84.8 | 3.2  | 9.6  | 87.2 |   |   |   |   |   |   |   |   |   |
| 45-59     | NW       | 87.2 | 7.6  | 5.2 | 87.6 | 7.4  | 5.1  |   |   |   |   |   |   |   |   |   |
|           | PT       | 15.5 | 52.7 | 31.8 | 21.4 | 44.5 | 34.1 |   |   |   |   |   |   |   |   |   |
|           | FT       | 2.8  | 9.5  | 87.7 | 3.7  | 9.0  | 87.3 |   |   |   |   |   |   |   |   |   |
| 60-75     | NW       | 96.4 | 2.9  | 0.7 | 94.9 | 3.3  | 1.8 |   |   |   |   |   |   |   |   |   |
|           | PT       | 26.0 | 61.1 | 12.9 | 32.4 | 55.0 | 12.6 |   |   |   |   |   |   |   |   |   |
|           | FT       | 7.3 | 16.8 | 75.9 | 9.8  | 14.1 | 76.1 |   |   |   |   |   |   |   |   |   |
| 75+       | NW       | 99.2 | 0.6  | 0.2 | 99.4 | 0.6  | 0.1 |   |   |   |   |   |   |   |   |   |
|           | PT       | 32.8 | 65.2 | 2.0 | 40.3 | 51.1 | 8.6 |   |   |   |   |   |   |   |   |   |
|           | FT       | 27.2 | 24.3 | 48.6 | 7.8 | 18.1 | 74.1 |   |   |   |   |   |   |   |   |   |
Various Calibration Summaries
Marriage by Education and Birth Year

Figure 3: Marriage Incidence Rate of Females by Education and Birth Year: Age 18-25. Source: PPI Staff calculations from the Panel Study of Income Dynamics (PSID)

Figure 4: Marriage Incidence Rate of Females by Education and Birth Year: Age 26-35. Source: PPI Staff calculations from the Panel Study of Income Dynamics (PSID)
Various Calibration Summaries
Marriage by Race with Same Education

Marriage Prevalence: All White Males by Female in Same Education Category

Marriage Prevalence: All Nonwhite Males by Female in Same Education Category
Various Calibration Summaries

Age-Wage Profiles

**Figure 2: Age-Wage Profiles by Education**

- **Constant 2012 Dollars**
  - 0
  - 10,000
  - 20,000
  - 30,000
  - 40,000
  - 50,000
  - 60,000
  - 70,000
  - 80,000

- **Age**
  - 18
  - 23
  - 28
  - 33
  - 38
  - 43
  - 48
  - 53
  - 58
  - 63
  - 68

- **Graph Legend**:
  - e<HS
  - e=HS
  - HS<e<Coll
  - Coll<e
  - Mean Attributes
Various Calibration Summaries
Capital Accumulation

![Graph showing capital accumulation by age and educational attainment]

- **W+A male <HS**
- **W+A male HS,>HS**
- **W+A male Coll+**
- **W+A female <HS**
- **W+A female HS,>HS**
- **W+A female Coll+**
- **B+H+O**

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Penn Wharton Budget Model: Overview
Validation of Model (SIM) Against Historical Data (CPS)

Types of Family Units

CPS-1995

- Total
- Non-family
- Single-Headed (Male Head)
- Single-Headed (Female Head)
- Dual-Headed-Family (Head)
- Dual-Headed-Family (Spouse)
- Kids Single Headed
- Kids Dual Headed

SIM-1995

- Total
- Non-family
- Single-Headed (Male Head)
- Single-Headed (Female Head)
- Dual-Headed-Family (Head)
- Dual-Headed-Family (Spouse)
- Kids Single Headed
- Kids Dual Headed

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Penn Wharton Budget Model: Overview
Validation of Model (SIM) Against Historical Data (CPS)

Types of Family Units

CPS-2000

- Total
- Non-family
- Single-Headed (Male Head)
- Single-Headed (Female Head)
- Dual-Headed Family (Head)
- Dual-Headed Family (Spouse)
- Kids Single Headed
- Kids Dual Headed

SIM-2000

- Total
- Non-family
- Single-Headed (Male Head)
- Single-Headed (Female Head)
- Dual-Headed Family (Head)
- Dual-Headed Family (Spouse)
- Kids Single Headed
- Kids Dual Headed
Validation of Model (SIM) Against Historical Data (CPS)

Types of Family Units
Validation of Model (SIM) Against Historical Data (CPS)

Types of Family Units

CPS-2010

SIM-2010

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Penn Wharton Budget Model: Overview
Validation of Model Against Historical Data

Married: White

CPS - Married Males by Age: White

SIM - Married Males by Age: White

CPS - Married Females by Age: White

SIM - Married Females by Age: White
Validation of Model Against Historical Data

Single: White

CPS - Single Males by Age: White

1995

2010

% of Population by Age

Age

CPS - Single Females by Age: White

1995

2010

% of Population by Age

Age

SIM - Single Males by Age: White

1995

2010

% of Population by Age

Age

SIM: Single Females by Age: White

2010

2010

% of Population by Age

Age

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Validation of Model Against Historical Data
Single Parents: White

CPS - Male Single Parents: White

CPS - Female Single Parents: White

SIM - Male Single Parents: White

SIM - Female Single Parents: White

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Penn Wharton Budget Model: Overview
Validation of Model Against Historical Data
Children by Family Type: White

**CPS - Children in Married Families: White**

- 1995
- 2010

**CPS - Children of Single Heads: White**

- 1995
- 2010

**SIM - Children in Married Families: White**

- 1995
- 2010

**SIM - Children of Single Heads: White**

- 1995
- 2010
Validation of Model Against Historical Data
Married: Nonwhite

CPS - Married Males by Age: Nonwhite

CPS - Married Females by Age: Nonwhite

SIM - Married Males by Age: Nonwhite

SIM - Married Females by Age: Nonwhite
Validation of Model Against Historical Data
Singles: Nonwhite

CPS - Single Males by Age: Nonwhite

CPS - Single Females by Age: Nonwhite

SIM - Single Males by Age: Nonwhite

SIM - Single Females by Age: Nonwhite
Validation of Model Against Historical Data
Single Parents: Nonwhite

CPS - Male Single Parents: Nonwhite

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1995 - Dotted line
2010 - Solid line

CPS - Female Single Parents: Nonwhite

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1995 - Dotted line
2010 - Solid line

SIM - Male Single Parents: Nonwhite

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1995 - Dotted line
2010 - Solid line

SIM - Female Single Parents: Nonwhite

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1995 - Dotted line
2010 - Solid line
Validation of Model Against Historical Data

Education: Males

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Penn Wharton Budget Model: Overview
Validation of Model Against Historical Data

Education: Females

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Projections
Population Subgroups
Projections
Population Subgroups
Projections
Population Subgroups
SIM-2035

- Total
- Non-family
- Single-Headed (Male Head)
- Single-Headed (Female Head)
- Dual-Headed-Family (Head)
- Dual-Headed-Family (Spouse)
- Kids Single Headed
- Kids Dual Headed
Projections
Population Subgroups

SIM-2040

- Total
- Non-family
- Single-Headed (Male Head)
- Single-Headed (Female Head)
- Dual-Headed-Family (Head)
- Dual-Headed-Family (Spouse)
- Kids Single Headed
- Kids Dual Headed
2. Production
Production is defined in terms of nominal output per person:

\[ y_{it} = P_t A_t K_t^\alpha (q_{it} h_{it})^{1-\alpha} \]

where \( h_{i,t} = 1 \) if person \( i \) worked in year \( t \); zero otherwise.

\[
\begin{align*}
P_t &= \text{Price index} \\
A_t &= \text{Multifactor productivity term} \\
K_t &= \text{Ttal Stock of Productive Capital} \\
q_{it} &= \text{Labor Efficiency} \\
q_{it} &= \text{Labor Efficiency of the } i^{th} \text{ Worker} \\
h_{it} &= \text{Work Hours of the } i^{th} \text{ Worker}
\end{align*}
\]
Summing across all persons, aggregate nominal output is:

\[ Y_t = \sum_i y_{it} = P_t A_t K_t^\alpha \sum_i q_{it}^{1-\alpha} = P_t A_t K_t^\alpha L_t^{1-\alpha} \]
Labor Input

Labor input is given by

\[ L_t = \left( \sum_i q_{it}^{1-\alpha} \right)^{\frac{1}{1-\alpha}} \]

where an individual’s labor input \( q_{i,t} \) is a function of \( X_{i,t} \), a set of \( m \) demographic attributes:

\[ q_{it} = \exp \left( \sum_{j=1}^{m} \theta_j X_{jit} \right) \]

However, the core labor regression used to determine labor input is specified in terms of âeffectiveâ labor input \( Z_{i,t} \) rather than \( q_{i,t} \):

\[ Z_{it} = \frac{W_{it}}{P_t A_t K_t^\alpha} = (1 - \alpha) q_{it}^{1-\alpha} \]
The regression model for effective labor input is:

$$\ln Z_{it} = f(X_{it}; \theta) = \ln (1 - \alpha) + (1 - \alpha) \ln q_{it} + u_{it}$$

$$= \ln (1 - \alpha) + (1 - \alpha) \sum_{j=1}^{k} \theta_j X_{jit} + u_{it}$$

Fitted values from this regression are augmented by drawing a perturbation term $\hat{e}_{i,t}$ from the distribution of estimated residuals from the regression.

Combining estimated coefficients $\hat{\theta}$, simulated demographic attributes $\tilde{X}_{i,t}$, and the "bootstrappedâ residual term $\hat{e}_{i,t}$ yields an individualâs simulated effective labor input:

$$\tilde{Z}_{it} = \exp \left( f \left( \tilde{X}_{it}; \hat{\theta} \right) + \hat{e}_{it} \right)$$

An individual’s nominal wage in year $t$ is given by:

$$\tilde{W}_{it} = P_t A_t K_t^\alpha \tilde{Z}_{it}$$
The individual’s simulated functional labor input is then:

\[ \tilde{q}_{it} = \left( \frac{\tilde{Z}_{it}}{1 - \alpha} \right)^{\frac{1}{1 - \alpha}} \]

Simulated aggregate labor is then:

\[ \tilde{L}_t = \left( \sum_i \tilde{q}_{it}^{1 - \alpha} \right)^{\frac{1}{1 - \alpha}} = \left( \sum_i \frac{\tilde{Z}_{it}}{1 - \alpha} \right)^{\frac{1}{1 - \alpha}} \]

And simulated aggregate nominal output is,

\[ \tilde{Y}_t = P_t A_t K_t^{\alpha} \tilde{L}_t^{1 - \alpha} = \frac{P_t A_t K_t^{\alpha}}{1 - \alpha} \sum_i \tilde{Z}_{it} \]
Estimating Multi-Factor Productivity, $A_t$
3. Policy Analysis
General Strategy

1. Create a policy module with detailed description of current law, i.e., the “baseline.” For example, for Social Security, the salient features of benefits are coded (including spousal benefits, survivor benefits, and many more features) along with payroll taxes up to the taxable maximum. For tax reform, individual-level tax forms are coded.

2. Policy module is interacted with Core Module

3. Policy module checked against historical data.

4. A set $S$ of policy choices, each with range $R$, are constructed, resulting in $S \times R$ new policy combinations.

5. The $S \times R$ policy combinations are simulated into the future (typically 75 years) using parallel cloud computing, with output saved to a JSON server.

6. Iteration tools on the production (public) website allows users to quickly observe the impact of policy changes.
The Social Security Trust Fund consists of excess revenues from Social Security taxes, which are invested in non-marketable Treasury bonds. Interest income from these bonds that is not used to pay benefits is also deposited in the Trust Fund.

The Trust Fund is expected to continue growing during the next few years as interest income exceeds Social Security’s non-interest revenue shortfall, although its value will decline in real terms (adjusted for inflation). As the difference between program costs and income from Social Security taxes grows larger, interest income will eventually be insufficient to cover the non-interest revenue shortfall. Trust Fund securities would then have to be redeemed to pay lawful benefits, implying an additional drain on the federal budget’s general fund.
Current Policies Simulated

Immigration

- **Increase Annual Net Legal Immigration**
  - No Change
  - 25%
  - 50%
  - 75%
  - 100%

- **Share of Skilled/Educated Immigrants**
  - No Change
  - 40%
  - 45%
  - 50%
  - 55%

- **Increase Deportations (-) or Offer Legal Status to Unauthorized Immigrants (+)**
  - -10%
  - -5%
  - 0%
  - 5%
  - 10%

**IMMIGRATION POLICY**

Employment includes all paid employees and self-employed workers who worked full time or part time during the year.

Click and drag in the plot area to zoom in; click on series titles in the legend to show or hide lines.
Future Policies Simulated

- Tax Reform (September, 2016)
- Health Care (Spring, 2017)
- Public Infrastructure (2017)
- Retirement Savings Accounts (2017)
- Labor Effectiveness (2017)
- Regulation (2017)
- Additional parts of government