Analyzing the Interplay Between Public-Pension Finances and Governmental Finances

Lessons from Linking an Economic Model to a Pension Fund Model

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Introduction

- We and other researchers have examined the investment-related risks to public pension funds and the sponsoring governments using stochastic simulation models.

- These models generally use simple investment return assumptions:
  - Returns follow normal distribution
  - Asset returns and government tax revenue are assumed to be uncorrelated
Introduction

- Research suggests that the real world differs from these simple assumptions:
  - Investment returns and tax revenue may be correlated (through business cycles)
  - Non-normality in asset returns
- Poor economy may cause
  - Returns to fall short of expectations
  - Tax revenue to fall short
  - Increase in required contribution may cause additional fiscal pressure
Model Structure and Linkage

We develop and link a small-scale macro-economic and investment-returns model to a pension fund simulation model and models of governmental tax revenue.
The Economic Scenario Generator (ESG)

- We built a small macroeconomic model that can generate internally consistent stochastic scenarios of growth in real gross domestic product (GDP) and returns from stock and bond investments.

- **GDP growth**
  - Two regimes: economic expansion and recession
  - Modeled as a Markov-switching process; the model captures the general historical pattern of expansions and recessions.

- **Stock return**
  - Two regimes: high-return-low-volatility periods; low-return-high-volatility periods.
  - The ESG allows for correlation between stock returns and GDP growth by aligning their regimes.

- **Bond return**
  - We did not model bond returns econometrically, because of their weak historical relationships to business cycles.
  - Instead, when we produce economic scenarios, we construct stochastic bond returns that have correlations to stock returns that are consistent with historical correlations.
Model Structure and Linkage

**Economic Scenario Generator**
- Real GDP
- Stock returns
- Bond returns
  - Eventually: inflation, more asset classes
  - Simulation period: 30 years
  - 2,000 runs in each simulation

**GDP growth and stock returns**

**Pension Simulation Model**

**Inputs:**
- Demographics
- Benefit rules
- Funding policies
- Actuarial assumptions
- Simulated investment returns

**Outputs:**
- Actuarial liability
- Asset value
- Cash flow
- Funded ratio
- Actuarially determined contribution (ADC)

**Tax Revenue: Trend and Cycle**
- Trend:
  - Taxes will stay constant relative to the economy over the long run (with cycles around the trend).

**GDP cycles and financial market cycles**

**Tax revenue cycles**:
- Income tax
- Sales tax
- Other

**Tax revenue of each type of tax = Trend + Cycle**

**Tax Revenue of Stylized Governments**
- Stylized governments:
  - Personal-income-tax-dominant state
  - Sales-tax-dominant state

**Fiscal Pressure**

Employer contribution (ERC) as a percentage of tax revenue (government is assumed to pay full ADC)

Risks:
- Very high ERC relative to tax revenue
- Sharp increases in ERC relative to tax revenue

**Required Employer contribution (Actuarially determined contribution)**
Modeling cyclical tax variability for individual taxes

- We estimate the cyclical relationships between taxes and the economy for
  - state personal income taxes,
  - the state general sales tax,
  - state selective sales taxes,
  - and all other state government taxes as a group.

- Individual taxes can exhibit different long-run behavior relative to the economy – for example, progressive income taxes generally will grow more quickly than the economy, while state sales tax bases have been declining relative to the economy.

- In our analyses below, we assume that politicians will adjust tax bases and rates to maintain their shares of the economy over the long run, but that there will be cycles around this trend.

### State and local government tax shares in 2015

<table>
<thead>
<tr>
<th></th>
<th>State government</th>
<th>Local government</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal income tax</td>
<td>36.9%</td>
<td>4.8%</td>
</tr>
<tr>
<td>General sales tax</td>
<td>31.4%</td>
<td>12.5%</td>
</tr>
<tr>
<td>Selective sales taxes</td>
<td>15.9%</td>
<td>4.8%</td>
</tr>
<tr>
<td>Property tax</td>
<td>1.7%</td>
<td>72.1%</td>
</tr>
<tr>
<td>Other</td>
<td>14.1%</td>
<td>5.8%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0%</strong></td>
<td><strong>100.0%</strong></td>
</tr>
</tbody>
</table>

Source: U.S. Census Bureau, 2015 Annual Survey of State and Local Government Finances
Cyclical components of main tax revenue sources and cyclical component of real GDP
Cyclical behavior of income tax also depends on how business cycles affect asset values and thereby capital gains from assets.
Estimated cyclical tax variability for individual taxes

- **Cyclical growth** rate of real tax revenues: a function of the cyclical growth rate of real GDP and, in the case of the personal income tax, the cyclical growth rate of real stock market values.
- **Trend tax growth**: the same as trend GDP growth (assumed to be 1.9% based on CBO projection)
- **Total tax growth** = Cyclical growth + trend growth

<table>
<thead>
<tr>
<th>Assumptions about trend and cyclical growth rates of tax revenues for simulation analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Growth rates in inflation-adjusted tax revenue</strong></td>
</tr>
<tr>
<td>Individual income tax</td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td><strong>Trend growth rate</strong></td>
</tr>
<tr>
<td><strong>Elasticity of cyclical change</strong></td>
</tr>
<tr>
<td>Real GDP growth</td>
</tr>
<tr>
<td>Real Stock returns</td>
</tr>
</tbody>
</table>
Constructing tax portfolios for stylized governments

Economic Scenario Generator
- Real GDP
- Stock returns
- Bond returns

[Eventually: inflation, more asset classes]
- Simulation period: 30 years
- 2,000 runs in each simulation

GDP growth and stock returns

All asset returns

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Required Employer contribution (Actuarially determined contribution)
Constructing tax portfolios for stylized governments

![Graph showing shares of individual income tax and general sales tax across states in 2015. The graph circles states with high sales-tax-dominant and high personal-income-tax-dominant states.]

- **Sales-tax-dominant states**
- **Personal-income-tax-dominant states**
Tax portfolios for stylized governments

<table>
<thead>
<tr>
<th></th>
<th>Personal income tax revenue</th>
<th>General sales tax revenue</th>
<th>Selective sales tax revenue</th>
<th>Other taxes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Personal income tax dominant state</strong></td>
<td>55%</td>
<td>20%</td>
<td>10%</td>
<td>15%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Sales tax dominant state</strong></td>
<td>0%</td>
<td>60%</td>
<td>25%</td>
<td>15%</td>
<td>100%</td>
</tr>
</tbody>
</table>
Pension simulation model

Pension Simulation Model

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**Economic Scenario**
- Real GDP
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**Fiscal Pressure**
Employer contribution (ERC) as a percentage of tax revenue (government is assumed to pay full ADC)
- Risks:
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Potential compounding risks from business cycles, correlated investment returns, and tax revenue

• With tax revenues, asset returns, and pension finances that are all generated within a coherent simulation framework, we can examine the compounding of risks from correlated investment returns and tax revenues.

• Comparing stylized governments with a baseline model with no linkage and alternative model structures:
  • how pension-related risks can be understated if the linkage is ignored
  • how the increase in risk can be decomposed.

• Two types of risks

  1) The required employer contributions become very high relative to fiscal resources available to the sponsoring government
  2) The required employer contributions rise sharply in a short period of time
The risk of high employer contributions

<table>
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<tr>
<th>Amortization method for unfunded liability</th>
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<td>1.3%</td>
<td>2.0%</td>
<td>4.9%</td>
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Note: In year 1, employer contribution as a percentage of total tax revenue under the three amortization methods are 8.67% (10-year open constant dollar), 7.25% (15-year open constant dollar), and 5% (30-year open constant percent of payroll).
The risk of high employer contributions

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Conclusion

• This paper shows how important it is to incorporate budgetary resources in pension fund risk analysis, and how that analysis can be deepened by modeling business cycles and investment returns together. Our work in this area is preliminary and can be extended and improved upon.

• The simulation results demonstrate that the pension-related risks are even larger than commonly understood under simple assumptions, and the risks can be further exacerbated by how state tax revenue structures respond to economic conditions.

• The choice of funding policies for public pension funds also has a significant impact on the risks that sponsoring governments face.

• Stress testing and risk reporting are, we hope, the wave of the future.
Appendix
### Simulation parameters based on forward-looking assumptions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Assumption on quarterly data (Annualized rates in parentheses except for the transition probabilities)</th>
<th>Target assumptions for annual data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Expansion period</td>
<td>Recession period</td>
</tr>
<tr>
<td>Transition probability</td>
<td>4.8% (expansion to recession)</td>
<td>32% (recession to expansion)</td>
</tr>
<tr>
<td>GDP growth (real)</td>
<td>Expected GDP growth</td>
<td>0.67% (2.7%)</td>
</tr>
<tr>
<td></td>
<td>Standard deviation of GDP growth</td>
<td>0.74% (1.48%)</td>
</tr>
<tr>
<td>Stock return (nominal)</td>
<td>Expected return</td>
<td>2.54% (10.6%)</td>
</tr>
<tr>
<td></td>
<td>Standard deviation</td>
<td>6.9% (13.8%)</td>
</tr>
<tr>
<td>Bond return (nominal)</td>
<td>Expected return</td>
<td>0.9% (3.6%)</td>
</tr>
<tr>
<td></td>
<td>Standard deviation</td>
<td>2% (4%)</td>
</tr>
<tr>
<td>Correlation between stock return and bond return</td>
<td></td>
<td>0.15</td>
</tr>
</tbody>
</table>

**Notes:**
1. Adjustments are made to the quarterly parameters estimated with historical data to ensure the simulated results for annual data (converted from simulated quarterly data) are consistent with the target assumptions for annual data. The variables that have been adjusted and their historical-data based estimates (all for quarterly data) are expected GDP growth in expansion (0.95%), GDP growth in recession (-0.55%), expected stock return in expansion (3.2%), expected stock return in recession (-1.4%), expected bond return (1.6%), standard deviation of bond return (5.1%). (Historical bond returns are for long-term corporate bond)
2. The target annual GDP growth is obtained from the 30-year projection of potential growth GDP made by CBO (2017). The target assumptions on annual stock and bond returns are generally consistent with the capital market assumptions used in Mennis, et. al (2017).
### Performance of our economic scenario generator

#### Summary statistics for historical and simulated data

<table>
<thead>
<tr>
<th>Economic regimes</th>
<th>Historical value for 1953-2015 (63 years)</th>
<th>Median of the simulated distribution (2,000 simulations)</th>
<th>Historical value's percentile in the simulated distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of recessions</td>
<td>10</td>
<td>10</td>
<td>52</td>
</tr>
<tr>
<td>Number of expansions</td>
<td>10</td>
<td>11</td>
<td>40</td>
</tr>
<tr>
<td>Average length of recession (quarters)</td>
<td>3.7</td>
<td>3.0</td>
<td>79</td>
</tr>
<tr>
<td>Average length of expansion (quarters)</td>
<td>20.2</td>
<td>19.4</td>
<td>57</td>
</tr>
<tr>
<td>GDP growth</td>
<td>Mean: 3.0%</td>
<td>3.1%</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation: 2.5%</td>
<td>2.2%</td>
<td>91</td>
</tr>
<tr>
<td>Stock return</td>
<td>Mean: 10.4%</td>
<td>10.9%</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation: 15.7%</td>
<td>17.2%</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Kurtosis (Measure of heavy-tailedness): 0.13</td>
<td>0.10</td>
<td>52</td>
</tr>
<tr>
<td>Bond return</td>
<td>Mean: 6.6%</td>
<td>6.6%</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation: 9.6%</td>
<td>10.6%</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Kurtosis (Measure of heavy-tailedness): 0.63</td>
<td>-0.16</td>
<td>88</td>
</tr>
</tbody>
</table>

Note: The kurtosis measure compares the "heavy-tailedness" of our simulated distributions to the normal distribution. Values greater than 1 mean our distribution has heavier tails than the normal distribution, and less than 1 mean the opposite.
How we use model parameters to calculate tax revenue growth in the simulation

### An example of the calculation of cyclical tax revenue growth in the simulation

<table>
<thead>
<tr>
<th>Elasticity with respect to</th>
<th>Hypothetical Cyclical GDP growth (c)</th>
<th>Hypothetical Cyclical Stock return (d)</th>
<th>Cyclical tax revenue growth (a)×(c) + (b)×(d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Categorical tax level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Individual income tax</td>
<td>1.0</td>
<td>0.2</td>
<td>1% × 1 + 2% × 0.2 = 1.4%</td>
</tr>
<tr>
<td>General sales tax</td>
<td>1.2</td>
<td>0</td>
<td>1% × 1.2 = 1.2%</td>
</tr>
<tr>
<td>Selective sales tax</td>
<td>0.5</td>
<td>0</td>
<td>1% × 0.5 = 1.2%</td>
</tr>
<tr>
<td>Other taxes</td>
<td>1.3</td>
<td>0</td>
<td>1% × 1.3 = 1.3%</td>
</tr>
</tbody>
</table>

Notes:
1. All rates are inflation-adjusted values.
2. Cyclical growth of GDP and stock return are defined as the difference between total growth rate and trend growth rate.
3. For each tax category, total tax revenue growth is the sum of the cyclical growth calculated in the table and the assumed trend growth (1.9% in the simulation).
Illustration of a single simulation (#2): real GDP growth and real stock return

Illustration of a single simulation (#2):
Growth of real tax revenue for two types of stylized government
Distribution of growth in real tax revenue
Risk of sharp increases in pension contributions relative to tax revenue

<table>
<thead>
<tr>
<th>Amortization method for unfunded liability</th>
<th>Constant growth of total tax revenue (equal to trend GDP growth)</th>
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<td>Simulated returns</td>
<td>Normally distributed returns</td>
</tr>
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<td>10-year open constant dollar</td>
<td>43.0%</td>
<td>44.1%</td>
<td>44.2%</td>
</tr>
<tr>
<td>15-year open constant dollar</td>
<td>20.9%</td>
<td>23.7%</td>
<td>23.3%</td>
</tr>
<tr>
<td>30-year open constant percent of payroll</td>
<td>0.5%</td>
<td>1.2%</td>
<td>1.1%</td>
</tr>
</tbody>
</table>

Note: In year 1, employer contribution as a percentage of total tax revenue under the three amortization methods are 8.67% (10-year open constant dollar), 7.25% (15-year open constant dollar), and 5% (30-year open constant percent of payroll).
Risk of large contribution increases in a short period of time

- Contribution-smoothing policies cannot make risks go away: They transfer risks from governments to pension plans

<table>
<thead>
<tr>
<th></th>
<th>Risk of sharp increase in employer contribution relative to tax revenue*</th>
<th>Employer contribution as a % of tax revenue in year 1</th>
<th>Median Present value at year 1 of total employer contribution for year 1-15**</th>
<th>Median Present value at year 1 of total employer contribution for year 16-30**</th>
<th>Probability of low funded ratio***</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-year open constant dollar</td>
<td>48.7%</td>
<td>8.7%</td>
<td>1.32</td>
<td>0.64</td>
<td>7.1%</td>
</tr>
<tr>
<td>15-year open constant dollar</td>
<td>31.4%</td>
<td>7.3%</td>
<td>1.23</td>
<td>0.67</td>
<td>11.7%</td>
</tr>
<tr>
<td>30-year open constant percent of payroll</td>
<td>3.1%</td>
<td>5.0%</td>
<td>1.00</td>
<td>0.68</td>
<td>30.9%</td>
</tr>
</tbody>
</table>

Notes:
* Probability of employer contribution rising more than 3 percent of total tax revenue in any 2-year period during the 30-year simulation period based on Model (4) (Cyclical growth of total tax revenue with simulated investment returns).
** The present value at year 1 of total employer contribution in year 1-15 under the policy "30-year open constant percent of payroll" is standardized to 1. All other values are standardized accordingly.
*** Probability of low funded ratio: the probability of funded ratio falling below 40% in any year during the 30 year simulation period.
## Simulation Model Comparisons

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>Tax revenue linked to GDP?</th>
<th>Asset return linked to GDP?</th>
<th>Based on stylized government?</th>
<th>Tax revenue linked to asset return?</th>
</tr>
</thead>
</table>
| (1)   | Unlinked model:  
- Constant growth of total tax revenue (equal to trend GDP growth).  
- Returns from normal distribution. | No | No | No | No |
| (2)   | Asset return linked only:  
- Constant growth of total tax revenue (equal to trend + cycle GDP growth).  
- Returns from regime-switching simulation model. | No | Yes | No | No |
| (3)   | Tax revenue linked only:  
- Cyclical growth of total tax revenue (equal to trend plus cycle GDP growth).  
- Returns from normal distribution. | Yes | No | No | No |
| (4)   | Both tax revenue and asset return linked:  
- Cyclical growth of total tax revenue (equal to trend plus cycle GDP growth).  
- Returns from regime-switching simulation model. | Yes | Yes | No | No |
| (5)   | Stylized government: sales-tax-dominant state  
- Cyclical growth of total tax revenue; estimated responsiveness to GDP growth.  
- Returns from regime-switching simulation model. | Yes | Yes | Yes | No |
| (6)   | Stylized government: income-tax-dominant state  
- Cyclical growth of total tax revenue; estimated responsiveness to GDP growth and asset return.  
- Returns from regime-switching simulation model. | Yes | Yes | Yes | Yes |