Efficient Electricity Portfolios for Switzerland and the United States

Workshop on Energy Economics and Technology

21 April 2006, TU Dresden
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6. Concluding Comments
1. Introduction

- Objective of Swiss energy policy (section 6, art. 89 octies of the Constitution) describes the desired provision of energy by the attributes: „sufficient“, „diversified“, „secure“, „economical“ and „environmentally compatible“.
- US National Energy Policy Group (NEPG) were established to „promote dependable, affordable and environmentally sound production of energy in the future“.
- Appropriate tool: Portfolio theory
- Different types of energy are like liabilities. Their uncertain „negative rate of return“ is their future increase in generation costs.
1. Introduction (cont’d)

• One important way to reduce the risk of cost fluctuations in a portfolio of liabilities is **diversification**.
• Diversification serves to increase the probability of one liability being neutralized by some other liability (that causes payables below expected value).

➢ **Applied to electricity: What mixes of generation technologies would be efficient?**
1. Introduction (cont’d)

1. Introduction (cont’d)

2. Portfolio Theory (cont’d)

Efficient Electricity Portfolios (EEP)

Expected return ($ER_p$) vs. Risk ($\sigma_p$)

GT = Generation Technology

Efficient mixes of GT1 - GT3

Efficient mixes of GT1 and GT2

Optimal mix of GT1 and GT2

Preference gradient

$EU$

A A’ C* C** B

GT3 GT1 GT2
2. Portfolio Theory

Swiss Portfolio consisting of four liabilities (2003)

\[ E(R_p) = \sum_{i=1}^{m} w_i E(R_i) \]  

(1)

\[ E(R_p, CH 2003) = w_1 E(R_1) + w_2 E(R_2) + w_3 E(R_3) + w_4 E(R_4) \]  

(2)

\[ \sigma_p(CH 2003) = \left( w_1^2 \sigma_1^2 + w_2^2 \sigma_2^2 + w_3^2 \sigma_3^2 + w_4^2 \sigma_4^2 \right)^{\frac{1}{2}} \right. 
+ 2w_1 w_2 \rho_{12} \sigma_1 \sigma_2 + 2w_1 w_3 \rho_{13} \sigma_1 \sigma_3 \\
+ 2w_1 w_4 \rho_{14} \sigma_1 \sigma_4 + 2w_2 w_3 \rho_{23} \sigma_2 \sigma_3 \\
+ 2w_2 w_4 \rho_{24} \sigma_2 \sigma_4 + 2w_3 w_4 \rho_{34} \sigma_3 \sigma_4 \right) \]  

(3)
3. Econometric Analysis

\[ R_{i,t} = \alpha_0 + \sum_{j=1}^{m} a_{i,t-j} \cdot R_{i,t-j} + u_{i,t} \]  \hfill (4)

\[ R_{Nucl,03} = b_{0Nucl,03} + x_{Nucl,02} b_{1Nucl,02} + x_{Nucl,01} b_{2Nucl,01} \]
\[ + x_{Nucl,00} b_{3Nucl,00} + x_{Nucl,99} b_{4Nucl,99} + trendb_{5Nucl} + \varepsilon_{Nucl,03} \]

\[ R_{Ror,03} = b_{0Ror,03} + x_{Ror,02} b_{1Ror,02} + trendb_{2Ror} + \varepsilon_{Ror,03} \]  \hfill (5)

\[ R_{Hs,03} = b_{0Hs,03} + x_{Hs,02} b_{1Hs,02} + trendb_{2Hs} + \varepsilon_{Hs,03} \]

\[ R_{Sol,03} = b_{0Sol,03} + x_{Sol,02} b_{1Sol,02} + x_{Sol,01} b_{2Sol,01} \]
\[ + x_{Sol,00} b_{3Sol,00} + x_{Sol,99} b_{4Sol,99} + trendb_{5Sol} + \varepsilon_{Sol,03} \]
3. Econometric Analysis (cont’d)

SURE

\[
\begin{bmatrix}
R_{Nucl,03} \\
R_{Ror,03} \\
R_{Hs,03} \\
R_{Sol,03}
\end{bmatrix}
= \begin{bmatrix}
X_1 & 0 & 0 & 0 \\
0 & X_2 & 0 & 0 \\
0 & 0 & X_3 & 0 \\
0 & 0 & 0 & X_4
\end{bmatrix}
\begin{bmatrix}
b_{Nucl,03} \\
b_{Ror,03} \\
b_{Hs,03} \\
b_{Sol,03}
\end{bmatrix}
+ \begin{bmatrix}
\epsilon_{Nucl,03} \\
\epsilon_{Ror,03} \\
\epsilon_{Hs,03} \\
\epsilon_{Sol,03}
\end{bmatrix}
\]

(6)

where e.g.

\[
X_1 = \begin{bmatrix}
1 & x_{Nucl,02} & x_{Nucl,01} & x_{Nucl,00} & x_{Nucl,99} & trend
\end{bmatrix}
\]

\[
b_{Nucl,03} = \begin{bmatrix}
b_{0Nucl,03} & b_{1Nucl,02} & b_{2Nucl,01} & b_{3Nucl,00} & b_{4Nucl,99} & b_{5Nucl}
\end{bmatrix}
\]
3. Econometric Analysis (cont’d)

\[ \Omega = E(\varepsilon \varepsilon') = \begin{bmatrix}
\sigma_{NuclNucl} I & \sigma_{NuclRor} I & \sigma_{NuclHs} I & \sigma_{NuclSol} I \\
\sigma_{RorNucl} I & \sigma_{RorRor} I & \sigma_{RorHs} I & \sigma_{RorSol} I \\
\sigma_{HsNucl} I & \sigma_{HsRor} I & \sigma_{HsHs} I & \sigma_{HsSol} I \\
\sigma_{SolNucl} I & \sigma_{SolRor} I & \sigma_{SolHs} I & \sigma_{SolSol} I 
\end{bmatrix} \] (7)
4. Efficient Frontiers for Swiss Power Generation

- Generation cost variables (deflated, basis: 2000 = 100)
- Components used for the current electricity production portfolios (annual data):
4. Efficient Frontiers for Swiss Power Generation (cont’d)

- Generation costs (GC) comprise:
  i. fuel costs
  ii. operating costs
  iii. capital user costs including depreciation
  iv. decommissioning and waste disposal (nuclear)
  v. external costs (mainly health and global warming; based on Friedrich (2002) and Hirschberg (1999))
4. Efficient Frontiers for Swiss Power Generation (cont’d)

<table>
<thead>
<tr>
<th>Year</th>
<th>Nuclear</th>
<th>Run of river</th>
<th>Storage hydro</th>
<th>Solar</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>4.97</td>
<td>2.59</td>
<td>5.69</td>
<td>80.76</td>
</tr>
<tr>
<td>2003</td>
<td>3.47</td>
<td>1.91</td>
<td>4.04</td>
<td>47.41</td>
</tr>
</tbody>
</table>

Comparison between 1995 and 2003 of Swiss generation costs taking account of external costs (using high cost scenario), in U.S. cents/kWh
4. Efficient Frontiers for Swiss Power Generation (cont’d)

<table>
<thead>
<tr>
<th></th>
<th>R</th>
<th>St.D.</th>
<th>$b_0$</th>
<th>$b_1$</th>
<th>$b_2$</th>
<th>$b_3$</th>
<th>$b_4$</th>
<th>Trend</th>
<th>Obs</th>
<th>R-sq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>-5.28</td>
<td>15.11</td>
<td>13.04***</td>
<td>-0.82***</td>
<td>-0.96***</td>
<td>-1.34***</td>
<td>-1.37***</td>
<td>-2.70***</td>
<td>9</td>
<td>0.78</td>
</tr>
<tr>
<td>Nuclear high</td>
<td>-4.74</td>
<td>12.11</td>
<td>4.23</td>
<td>-0.74***</td>
<td>-0.93***</td>
<td>-1.22***</td>
<td>-1.38***</td>
<td>-1.81***</td>
<td>9</td>
<td>0.74</td>
</tr>
<tr>
<td>Nuclear low</td>
<td>-5.28</td>
<td>15.11</td>
<td>13.04***</td>
<td>-0.82***</td>
<td>-0.96***</td>
<td>-1.34***</td>
<td>-1.37***</td>
<td>-2.70***</td>
<td>9</td>
<td>0.78</td>
</tr>
<tr>
<td>Run of river</td>
<td>-0.04</td>
<td>18.69</td>
<td>32.25</td>
<td>-0.67***</td>
<td>-</td>
<td>-</td>
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<td>-1.95</td>
<td>9</td>
<td>0.51</td>
</tr>
<tr>
<td>Run of river high</td>
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<td>18.77</td>
<td>32.72</td>
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<td>-1.98</td>
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<tr>
<td>Run of river low</td>
<td>-0.04</td>
<td>18.70</td>
<td>32.25</td>
<td>-0.67***</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-1.95</td>
<td>9</td>
<td>0.51</td>
</tr>
</tbody>
</table>

*** significant at 1 percent level, ** significant at 5 percent level, * significant at 1 percent level

$R = X\beta + \varepsilon$, $\varepsilon\varepsilon' = \Omega$ (Covariance matrix of residuals)

Example: $\Delta\text{Storage}_{\text{hydro}} = b_0 \text{const} + b_1 \Delta\text{Storage}_{\text{hydro},-1} + b_2 \text{Trend} + u_t$
4. Efficient Frontiers for Swiss Power Generation (cont’d)

<table>
<thead>
<tr>
<th></th>
<th>$R$</th>
<th>St.D.</th>
<th>$b_0$</th>
<th>$b_1$</th>
<th>$b_2$</th>
<th>$b_3$</th>
<th>$b_4$</th>
<th>Trend</th>
<th>Obs</th>
<th>R-sq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage hydro</td>
<td>-0.69</td>
<td>14.93</td>
<td>27.95</td>
<td>-0.69***</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-1.91</td>
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<td>0.23</td>
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<tr>
<td>Storage hydro high</td>
<td>-1.00</td>
<td>12.65</td>
<td>24.71</td>
<td>-0.72***</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-1.73</td>
<td>9</td>
<td>0.22</td>
</tr>
<tr>
<td>Storage hydro low</td>
<td>-0.69</td>
<td>14.93</td>
<td>27.95</td>
<td>-0.69***</td>
<td>-</td>
<td>-</td>
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<td>-1.91</td>
<td>9</td>
<td>0.23</td>
</tr>
<tr>
<td>Solar</td>
<td>-7.01</td>
<td>0.77</td>
<td>-33.32***</td>
<td>-0.70***</td>
<td>-0.55**</td>
<td>-0.62*</td>
<td>-0.54**</td>
<td>0.64***</td>
<td>9</td>
<td>0.62</td>
</tr>
<tr>
<td>Solar high</td>
<td>-6.95</td>
<td>0.76</td>
<td>-33.00***</td>
<td>-0.73***</td>
<td>-0.56**</td>
<td>-0.61*</td>
<td>-0.55**</td>
<td>0.66***</td>
<td>9</td>
<td>0.63</td>
</tr>
<tr>
<td>Solar low</td>
<td>-7.01</td>
<td>0.77</td>
<td>-33.31***</td>
<td>-0.70***</td>
<td>-0.55**</td>
<td>-0.62*</td>
<td>-0.54**</td>
<td>0.64***</td>
<td>9</td>
<td>0.62</td>
</tr>
</tbody>
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$R = XB + \varepsilon$, $\varepsilon\varepsilon' = \Omega$ (Covariance matrix of residuals)

Example: $\Delta \text{Storage}_\text{hydro}_t = b_0 \text{const} + b_1 \Delta \text{Storage}_\text{hydro}_{t-1} + b_2 \text{Trend} + u_t$,
4. Efficient Frontiers for Swiss Power Generation (cont’d)

Swiss Efficient Electricity Portfolio
(2003, SURE-based, no constraint, without external costs)
4. Efficient Frontiers for Swiss Power Generation (cont’d)

Swiss Efficient Electricity Portfolios (2003, SURE-based, with constraint, without external costs)
4. Efficient Frontiers for Swiss Power Generation (cont’d)

Swiss Efficient Electricity Portfolios
(2003, SURE-based, with constraint, with high external costs)

Maximum Expected Return Portfolio (MER)
Max. $E(R_p) = 4.83$, St.D. = 11.63
96% Nuclear
4% Solar

Minimum Variance Portfolio (MV)
$E(R_p) = 3.45$, Min St.D. = 9.60
60% Nuclear
32% Storage hydro
4% Run of river
4% Solar

Actual Portfolio 2003 (AP2003)
Return = 1.82, St.D. = 10.41
40% Nuclear
24% Run of river
32% Storage hydro
4% Solar

Constraints imposed (maximum shares):
Run of river ≤ 24%, Storage hydro ≤ 32% & Solar ≤ 4%
5. Efficient Frontiers for US Power Generation

- Generation cost variables (deflated, basis: 2000 = 100)
- Components used for the current electricity production portfolios (annual data):
5. Efficient Frontiers for US Power Generation (cont’d)

• Like in the Swiss data set, generation costs comprise: fuel costs, operating costs, capital user costs (including depreciation) and decommissioning and waste disposal (nuclear)

• No external cost data for the US are available, therefore external cost data from the UK were used (European Commission, 2003)

• Useful proxy, since both markets are similar
5. Efficient Frontiers for US Power Generation (cont’d)

<table>
<thead>
<tr>
<th>Year</th>
<th>Oil</th>
<th>Coal</th>
<th>Gas</th>
<th>Nuclear</th>
<th>Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>11.27</td>
<td>11.44</td>
<td>6.20</td>
<td>5.77</td>
<td>5.44</td>
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<tr>
<td>2003</td>
<td>10.10</td>
<td>8.99</td>
<td>7.56</td>
<td>3.80</td>
<td>4.35</td>
</tr>
</tbody>
</table>

Comparison between 1995 and 2003 of U.S. generation costs taking account of external costs (using high cost scenario), in U.S. cents/kWh
5. Efficient Frontiers for US Power Generation (cont’d)

<table>
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<th>$b_4$</th>
<th>$b_5$</th>
<th>Trend</th>
<th>Obs</th>
<th>R-sq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>-4.44</td>
<td>14.60</td>
<td>-109.70***</td>
<td>-0.53*</td>
<td>-1.17***</td>
<td>-0.64*</td>
<td>-0.90**</td>
<td>-0.3</td>
<td>6.4***</td>
<td>17</td>
<td>0.60</td>
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<tr>
<td>Oil_high</td>
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<td>-0.88***</td>
<td>-1.24***</td>
<td>-1.03***</td>
<td>-1.14***</td>
<td>-0.5*</td>
<td>4.74***</td>
<td>17</td>
<td>0.67</td>
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<tr>
<td>Oil_low</td>
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<td>-105.23***</td>
<td>-0.82***</td>
<td>-1.29***</td>
<td>-0.97***</td>
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<td>-0.5</td>
<td>5.53***</td>
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<td>0.65</td>
</tr>
<tr>
<td>Gas</td>
<td>-3.24</td>
<td>10.10</td>
<td>-19.01</td>
<td>0.27</td>
<td>-0.80 ***</td>
<td>0.29</td>
<td>-</td>
<td>-</td>
<td>1.19</td>
<td>17</td>
<td>0.65</td>
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<tr>
<td>Gas_high</td>
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<td>8.21</td>
<td>-30.84***</td>
<td>0.05</td>
<td>-0.92 ***</td>
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<td>1.81 ***</td>
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<td>Gas_low</td>
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<td>-</td>
<td>-</td>
<td>1.11</td>
<td>17</td>
<td>0.66</td>
</tr>
</tbody>
</table>

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$R = XB + \varepsilon, \quad \varepsilon \varepsilon' = \Omega$ (Covariance matrix of residuals)

Example: $\Delta\text{Nuclear}_t = b_0 \text{const} + b_1 \Delta\text{Nuclear}_{t-1} + b_2 \text{Trend} + u_t$
5. Efficient Frontiers for US Power Generation (cont’d)

<table>
<thead>
<tr>
<th></th>
<th>$R$</th>
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<th>$b_4$</th>
<th>$b_5$</th>
<th>Trend</th>
<th>Obs</th>
<th>R-sq</th>
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</thead>
<tbody>
<tr>
<td>Nuclear</td>
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<td>5.40</td>
<td>-7.39***</td>
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<td>0.25</td>
<td>17</td>
<td>0.03</td>
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<td>-6.54**</td>
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<tr>
<td>Nuclear_low</td>
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<td>-6.93**</td>
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<td>0.21</td>
<td>17</td>
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<td>Wind</td>
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<td>0.50**</td>
<td>-</td>
<td>-</td>
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<td>0.40**</td>
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<td>0.60</td>
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<td>Wind_high</td>
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<td>5.82</td>
<td>-3.40</td>
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<td>3.05</td>
<td>-3.97***</td>
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<td>0.29</td>
<td>17</td>
<td>0.29</td>
</tr>
</tbody>
</table>

*** significant at 1 percent level, ** significant at 5 percent level, * significant at 1 percent level

$R = XB + \varepsilon$, $\varepsilon\varepsilon' = \Omega$ (Covariance matrix of residuals)

Example: $\Delta\text{Nuclear}_t = b_0\text{const} + b_1\Delta\text{Nuclear}_{t-1} + b_2\text{Trend} + u_t$
5. Efficient Frontiers for US Power Generation (cont’d)

**U.S. Efficient Electricity Portfolio**
(2003, SURE-based, no constraint, without external costs)

**Maximum Expected Return Portfolio (MER)**
Max. $E(R_p) = 12.28$, St.D. = 3.90
100% Wind

**Minimum Variance Portfolio (MV)**
$E(R_p) = 7.83$, Min St.D. = 1.54
53% Coal
27% Wind
20% Nuclear

**Actual Portfolio 2003 (AP2003)**
Return = 5.73, St.D. = 3.20
56% Coal
21% Nuclear
18% Gas
3% Oil
2% Wind
5. Efficient Frontiers for US Power Generation (cont’d)

U.S. Efficient Electricity Portfolios
(2003, SURE-based, with constraint, without external costs)

Maximum Expected Return Portfolio (MER)
Max. $E(R_p) = 7.10$, St.D. = 2.84
95% Coal
5% Wind

Minimum Variance Portfolio (MV)
$E(R_p) = 6.42$, Min St.D. = 1.86
66% Coal
29% Nuclear
5% Wind

Actual Portfolio 2003 (AP2003)
Return = 5.73, St.D. = 3.20
56% Coal
21% Nuclear
18% Gas
3% Oil
2% Wind

Constraints imposed (maximum shares):
$Wind \leq 5\%$
5. Efficient Frontiers for US Power Generation (cont’d)

U.S. Efficient Electricity Portfolios
(2003, SURE-based, with constraint, with high external costs)

Maximum Expected Return Portfolio (MER)
Max. $E(R_p) = 5.03$, St.D. = 1.24
95% Coal
5% Wind

Minimum Variance Portfolio (MV)
$E(R_p) = 4.99$, Min St.D. = 0.94
81% Coal
7% Oil
7% Nuclear
5% Wind

Actual Portfolio 2003 (AP2003)
Return = 4.64, St.D. = 2.26
56% Coal
21% Nuclear
18% Gas
3% Oil
2% Wind
6. Concluding Comments

- In view of correlated error terms, a SURE procedure was adopted.

- For Switzerland the unconstrained MER and MV portfolios contain Solar exclusively. The US MER portfolio is made up of 100 percent Wind, while the MV portfolio is more diversified with 53 percent Coal, 27 percent Wind and 20 percent Nuclear.

- With feasibility constraints imposed, and taking account of social costs, the MER portfolio for Switzerland contains 96 percent Nuclear and 4 percent Solar.

- For the United States, MER shares are 95 percent Coal and 5 percent Wind.
6. Concluding Comments (cont’d)

• For a risk averse population (such as the Swiss and the US), the MV portfolio may be appropriate.

• The Swiss MV portfolio contains 60 percent Nuclear, 32 percent Storage hydro, 4 percent Run of river and 4 percent Solar (high external costs).

• For the US, one finds that Coal with 81 percent contributes importantly to the MV portfolio, distantly followed by 7 percent Oil, 7 percent Nuclear and 5 percent Wind.

• Interestingly, Gas does not play any role in the determination of efficient electricity portfolios in the United States.