Does a Welfare Maximizing Quality Regulation Guarantee Timely Network Replacement Investments? - Theoretical Model and Experiment

7th Conference on Energy Economics and Technology
Dresden University of Technology
Tuesday, 15 May 2012

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Introduction & Preliminary Results

Model & Experiment

Experimental Results

Conclusion
**Introduction & Preliminary Results**

- part of the DSOs assets reaches the beginning of the wear-out period of their bathtub curves

- possible consequences:
  - increases in the failure rates ($F_{AB1}$)
  - increases in the failure rate of the whole grid ($F_{\text{grid}}$);
  - higher probability of service interruptions
  - reduce the quality level ($q_{\text{grid}}$) in the entire network

- WMQR (ideal Welfare Maximizing Quality Regulation): incentivize the DSO to replace the assets before $q_{\text{grid}}$ starts to decline
Introduction & Preliminary Results

WMQR

WMQR’s goal: $t_{ABn} = n$ to hold $q_{target}$

DSO

profitmax. Owner ($P$)

(real world)

tries to transfer the

“right incentives”

by a standard
labour contract $K$

(wagemax. Asset Manager ($A$)

could try to transfer the

“right incentives”

by an alternative
labour contract $L$

Investment activity of A’s predecessor in his last year $[I=Invest, N=not~invest]$
Agenda

• Introduction & Preliminary Results

• Model & Experiment

• Experimental Results

• Conclusion
Model & Experiment

1) **Model:** predict **only** the rational investment behaviour of a wage maximizing asset manager (A) under WMQR with $K$ and $L$

a) generally

![Diagram showing F_grid over time with expiration of the contract and inv. behaviour under WMQR with K (K_I and K_N) and L (L_I and L_N).](image)
components of the real world standard labour contract K included in the model:

- 5 years
- fixed salary $f$
- annual bonus up to 25% from fixed salary

\[ f \times 0.25 \min \left( \frac{\Pi}{\bar{\Pi}}, 1 \right) \]

\( \bar{\Pi} = \text{profit goal set by the owner} \)

\( \Pi = \text{actual profit done by the asset manager} \)

components of the alternative (not real world) labour contract of L included in the model:

- components of K + an annual bonus one year after the standard contract ends (i.e. in year 6)
b) more specific (justification of the rational investment behaviour of the assumed wage maximizing A)

\[ f_{01} + f_{01} \times 0.25^* \left( \pi_{\text{Rest01}} + \pi_{ABp} - l/A_{ABp} - 0.1p_{ABp} + \pi_{AB1} - 0.1p_{AB1} \right) / \overline{\Pi}_{01} \]

\[ f_{01} + f_{01} \times 0.25^* \left( \pi_{\text{Rest01}} + \pi_{ABp} - l/A_{ABp} - 0.1p_{ABp} + \pi_{AB1} - 0.1p_{AB1} + l*r_{AB1} \right) / \overline{\Pi}_{01} \]

\[ f_{12} + f_{12} \times 0.25^* \left( \pi_{\text{Rest12}} + \pi_{AB1} - l/A_{AB1} - 0.1p_{AB1} + \pi_{AB5} - 0.1p_{AB5} + l*r_{AB5} \right) / \overline{\Pi}_{12} \]

\[ f_{12} + f_{12} \times 0.25^* \left( \pi_{\text{Rest12}} + \pi_{AB1} + l*r_{AB1} - 0.9p_{AB1} + \pi_{AB5} - 0.1p_{AB5} + l*r_{AB5} \right) / \overline{\Pi}_{12} \]

\[ f_{12} + f_{12} \times 0.25^* \left( \pi_{\text{Rest12}} + \pi_{AB1} + l*r_{AB1} - 0.9p_{AB1} + \pi_{AB5} - 0.1p_{AB5} + l*r_{AB5} \right) / \overline{\Pi}_{12} \]

\[ \Sigma \text{ max.} \]

\[ \Sigma \text{ ......} \]

\[ \Sigma \text{ ......} \]

\[ \Sigma \text{ ......} \]

\[ \Sigma \text{ ......} \]

° in case of WMQR+KN the term \( l/A_{ABp} \) disappears and \(-0.1p_{ABp}\) changes to \(-0.9p_{ABp}\)
in case of WMQR+LN see statement on WMQR+KN the slide before

→ from an overall welfare maximization point of view:

L is always better (100% I_{AB1}/I_{AB5}) than K (0% I_{AB1}/I_{AB5}) in the model!
2.) **Advantage of the experiment** (in contrast to the model):

- additionally it might be observed “non-own total wage maximizing behaviour”

<table>
<thead>
<tr>
<th>possible observable Investment Behaviour for AB1/AB5 in KI KN LI LN</th>
<th>Prediction by the <em>std. model</em></th>
<th>Types of decision makers as possible explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>yes (100%)</td>
<td><em>own total wage maximizer (std. model assumption)</em></td>
<td></td>
</tr>
<tr>
<td>no (0%)</td>
<td>EFF</td>
<td></td>
</tr>
<tr>
<td>no (0%)</td>
<td>SPI</td>
<td>Distributional preference types</td>
</tr>
<tr>
<td>no (0%)</td>
<td>IAV</td>
<td></td>
</tr>
<tr>
<td>no (0%)</td>
<td>ILO</td>
<td></td>
</tr>
<tr>
<td>no (0%)</td>
<td>indirect reciprocal, conformal</td>
<td>Behavioural types</td>
</tr>
<tr>
<td>no (0%)</td>
<td>guilt averse</td>
<td></td>
</tr>
<tr>
<td>no (0%)</td>
<td>myopic</td>
<td></td>
</tr>
<tr>
<td>no (0%)</td>
<td>non explainable</td>
<td></td>
</tr>
</tbody>
</table>

- find out which types are responsible for “non-own total wage maximizing behaviour”
- results I/I (%) for K and I/I (%) L are more realistic (compared to the model)!
3) **Experimental procedure**

- 120 students (participants) get the decision tree (60 get KI and KN, 60 get LI and LN)
- e.g. in K for KI and for KN:
  - all possible \( \sum \ldots \text{in KI} > \) all possible \( \sum \ldots \text{in KN} \)
  - each participant gets following information before he makes his decision:

  ```
  \[
  \begin{array}{c|c}
  KI & KN \\
  \hline
  \ldots/I & \ldots/I \\
  \ldots/I & \ldots/N \\
  \ldots/N & \ldots/I \\
  \ldots/N & \ldots/N \\
  \end{array}
  \]
  ```

  - Doing this:
    - KI is payoff relevant for another participant (successor) leads to KI (50% chance) or KN (50% chance) is payoff relevant for another participant (successor)
    - KN is payoff relevant for another participant (successor)

  » therewith he is reminded of his own potentially social preferences (regarding the payoff of his successor)

  **b)** whether his KI or KN is payoff- relevant for him depends on the decision of another participant (his predecessor) in the spirit of a)
Agenda

• Introduction & Preliminary Results

• Model & Experiment

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Experimental Results

• Not all participants are perfect “own expected total wage maximizers”
  – only 22% in K and 9.5% in L

• Explanation for “non-own expected total wage maximizing behaviour“:
  – Distributional preference types → no
  – Behavioural types → yes
    • in K: 78%; thereof 57% myopic type, 32% non-explainable type, 9% indirect reciprocal/conformal type, 2% guilt averse type
    • in L: 90.5%; thereof 46% non-explainable type, 26% myopic type, 21% indirect reciprocal/conformal type; 7% guilt averse type

• L is better than K from an overall welfare maximization point of view (9.5% vs. 0%)
Agenda

- Introduction & Preliminary Results
- Experimental Design
- Experimental Results

- Conclusion
**Conclusion**

WMQR

WMQR’s goal: \( t_{ABn} = n \) to hold \( q_{\text{target}} \)

**DSO**

```
profitmax. Owner (P) → “right incentives”
```

(real world)

tries to transfer the

“right incentives”

by a standard labour contract \( K \)

Wagemax. Asset Manager (A)

Investment activity of A’s predecessor in his last year

\[
I = \text{Invest}, \quad N = \text{not invest}
\]

**0% model**

0% experiment

**100% model**

9.5% experiment

\[ 100% \] model

\[ 0% \] model

\[ 0% \] model

\[ 100% \] model
Backup
Agenda

- perfectly working Quality Regulation (pwQR)
  - Necessity
  - Configuration for the rational (profit-maximizing) owner

- Investment behaviour of the rational (wage-maximizing) Asset Manager under pwQR
  - Given a standard labour contract
  - Given an alternative labour contract

- Model Extensions and Experiment
pwQR: Necessity

\[ F_{Net} \rightarrow q_{Net} \]

(cause by \( F_{AB1} \))

\[ F_{Net} \rightarrow q_{Net} = q_{target} \]

Useful life period

wear-out period

\( t_{AB1} \) with pwQR

\( t_{AB1} \) without pwQR

Volker Wannack, Enerday, 15/05/2012
pwQR: Necessity

- Plain Assumptions:
  - Costs (maintenance-; interest charges…) steady
  - Argumentation: maintenance-budget, steady interest charges…
  - Determination: \( t_{AB1} \text{ without pwQR} = 8 \) instead of \( 1 < t_{AB1} \text{ without pwQR} < 8 \)
  - Argumentation: crucially \( t_{AB1} \text{ with pwQR} < t_{AB1} \text{ without pwQR} \)
    - (since hypothesis: costs = steady, \( t_{AB1} \text{ without pwQR} = 8 \) would arise automatically)

→ Owner (VNB) maximizes entire profit when \( t_{AB1} \text{ without pwQR} = 8 \)

Math.:

\[
\Pi t_{AB1} = 1 = \int_0^\infty \Pi_{Re, st} e^{-rt} dt + \int_0^\infty (R - C) e^{-rt} dt - \int_0^\infty \frac{I(t)}{A} e^{-rt} dt
\]

\[
\Pi t_{AB1} = 2 = \int_0^\infty \Pi_{Re, st} e^{-rt} dt + \int_0^\infty (R - C) e^{-rt} dt - \int_2^\infty \frac{I(t)}{A} e^{-rt} dt + \int_0^2 Ire^{-rt} dt
\]

\[
\Pi t_{AB1} = 3 = \int_0^\infty \Pi_{Re, st} e^{-rt} dt + \int_0^\infty (R - C) e^{-rt} dt - \int_3^\infty \frac{I(t)}{A} e^{-rt} dt + \int_0^2 Ire^{-rt} dt
\]

\[
\Pi t_{AB1} = 8
\]
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• Model Extensions and Experiment
Volker Wannack, Enerday, 15/05/2012

pwQR: Configuration for owner

- **pwQR target:**
  - Create incentives for owners for $t_{AB1}=1$, so that $q_{Net\ const} = q_{target}$
  - Precise: $\prod t_{AB1} = 1 > \prod t_{AB1} = 2 > \ldots > \prod t_{AB1} = 8$

- **pwQR configuration:**
  1. Implement penalty $p$: $\Pi t_{AB1} = 1 = \int_0^\infty \Pi_{Rest} e^{-rt} dt + \int_0^\infty (R-C) e^{-rt} dt - \int_0^\infty \frac{I}{A}(t) e^{-rt} dt - \int_0^\infty 0.1 pe^{-rt} dt$
  2. Define $p$, so that $\Pi t_{AB1} = 1 > \Pi t_{AB1} = 2 > \ldots > \Pi t_{AB1} = 8$

  - E.g.: $\Pi t_{AB1} = 1 > \Pi t_{AB1} = 2$
  
  \[ p = 1.25 \left( \frac{I}{A} + Ire^r + X \right) \]

  → under pwQR the owner always chooses (by pwQR intendedly welfare-optimized Investment moment) $t_{AB1}=1$
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• Model Extensions and Experiment
Asset Manager’s Investment behaviour under pwQR and standard labour contract

• Standard labour contract:
  – 5-year-contract
  – Fixed salary
  – Annual profit-sharing up to 25% of fixed salary
  – (fixed company pension; DW)
Asset Manager’s Investment behaviour under pwQR and standard labour contract

- Investment behaviour (under pwQR + standard labour contract)

\[ F_{Net} \]

\[ t_{AB1} \]
\[ t_{AB2} \]
\[ t_{AB3} \]
\[ t_{AB4} \]
\[ t_{AB5} \]

\[ w_{tAB1=1} \]
\[ w_{tAB1=2} \]
\[ w_{tAB1=3} \]
\[ w_{tAB1=4} \]
\[ w_{tAB1=5} \]

\[ w_{tAB2=1} \]
\[ w_{tAB2=2} \]
\[ w_{tAB2=3} \]
\[ w_{tAB2=4} \]
\[ w_{tAB2=5} \]

\[ w_{tAB3=1} \]
\[ w_{tAB3=2} \]
\[ w_{tAB3=3} \]
\[ w_{tAB3=4} \]
\[ w_{tAB3=5} \]

\[ w_{tAB4=1} \]
\[ w_{tAB4=2} \]
\[ w_{tAB4=3} \]
\[ w_{tAB4=4} \]
\[ w_{tAB4=5} \]

\[ w_{tAB5=1} \]
\[ w_{tAB5=2} \]
\[ w_{tAB5=3} \]
\[ w_{tAB5=4} \]
\[ w_{tAB5=5} \]

\[ \text{in the interest of pwQR} \]
\[ \text{not in the interest of pwQR} \]

\[ \text{in the interest of the owner} \]
\[ \text{not in the interest of the owner} \]
Asset Manager’s Investment behaviour under pwQR and standard labour contract

- Using the example of AB₅: Why $w_{tAB5=5} < w_{tAB5=\ell}$?

\[
W_{tAB5 = 5} = 5 = \int_{4}^{5} f e^{-rt} dt + \int_{4}^{5} f \cdot 0.25 \min (\frac{\Pi_{rest} + (R(t) - C) - 0.1p}{\Pi}, 1) e^{-rt} dt
\]

\[
W_{tAB5 = \ell} = \ell = \int_{4}^{5} f e^{-rt} dt + \int_{4}^{5} f \cdot 0.25 \min (\frac{\Pi_{rest} + (R(t) - C) + I \cdot r - 0.1p}{\Pi}, 1) e^{-rt} dt
\]
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Asset Manager’s Investment behaviour under pwQR and alternative labour contract

• Alternative labour contract:
  – As ever + profit sharing

    one period after expiration of contract

    \[ \int_{5}^{6} f \times 0.25 \min\left(\frac{\Pi}{\Pi}, 1\right) e^{-rt} \, dt \]

• Investment behaviour (under pwQR + alternative labour contract)
  – As ever:

    \[ t_{AB1=1}, \quad da \quad w_{t \, AB1=1} \quad \text{max} \]

    \[ t_{AB2=2}, \quad da \quad w_{t \, AB2=2} \quad \text{max.} \]

    \[ t_{AB3=3}, \quad da \quad w_{t \, AB3=3} \quad \text{max.} \]

    \[ t_{AB4=4}, \quad da \quad w_{t \, AB4=4} \quad \text{max.} \]

  – Crucial modification:

    \[ t_{AB5=5}, \quad da \quad w_{t \, AB5=5} \quad \text{max} \]

    (before: \[ t_{AB5=/}, \quad da \quad w_{t \, AB5=/} \quad \text{max} \]) \rightarrow \text{Why?} \rightarrow
Asset Manager’s Investment behaviour under pwQR and alternative labour contract

\[ W_{tAB5} = 5 = \int_{4}^{5} f e^{-rt} \, dt \]

\[ + \int_{4}^{5} f * 0,25 \min\left(\frac{\Pi_{rest} + (R(t) - C) - 0,1p}{\Pi},1\right) e^{-rt} \, dt \]

\[ + \int_{5}^{6} f * 0,25 \min\left(\frac{\Pi_{rest} + (R(t) - C) - \frac{I}{A} - 0,1p}{\Pi},1\right) e^{-rt} \, dt \]

\[ W_{tAB5} = I = \int_{4}^{5} f e^{-rt} \, dt \]

\[ + \int_{4}^{5} f * 0,25 \min\left(\frac{\Pi_{rest} + (R(t) - C) + I * r - 0,1p}{\Pi},1\right) e^{-rt} \, dt \]

\[ + \int_{5}^{6} f * 0,25 \min\left(\frac{\Pi_{rest} + (R(t) - C) - 0,9p}{\Pi},1\right) e^{-rt} \, dt \]
Agenda

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• Model Extensions and Experiment
Model Extensions and Experiment

1. Model extension
   - 10% probability (instead of previously 0%) that error rate overlies the penalty threshold ($q_{\text{target}}$) in “useful life period” of $AB_n$
   - 90% probability (instead of previously 100%) that error rate overlies the penalty threshold ($q_{\text{target}}$) in “wear-out period” of $AB_n$
   \[\Rightarrow\] Investment behaviour of owner and manager stays the same

2. Economical Experiment shall examine following:
   - Is the investment behaviour of a “real life manager” similar to the theoretically assumed rational manager’s?
   \[\Rightarrow\] *Test subjects*: not managers, but 120 students
Model Extensions and Experiment

- **2x2 factorial design of the experiment - overview**

<table>
<thead>
<tr>
<th>Predecessor</th>
<th>Standard labour contract (K)</th>
<th>Alternative labour contract (L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invested (I) (in his last year)</td>
<td>(KI)</td>
<td>(LI)</td>
</tr>
<tr>
<td>30 Stud.</td>
<td>30 Stud.</td>
<td>30 Stud.</td>
</tr>
<tr>
<td>Inv. behaviour</td>
<td>Inv. behaviour</td>
<td>Inv. behaviour</td>
</tr>
<tr>
<td>Predecessor did <strong>Not Invest</strong> (N) (in his last year)</td>
<td>(KN)</td>
<td>(LN)</td>
</tr>
<tr>
<td>30 Stud.</td>
<td>30 Stud.</td>
<td>30 Stud.</td>
</tr>
<tr>
<td>Inv. behaviour</td>
<td>Inv. behaviour</td>
<td>Inv. behaviour</td>
</tr>
</tbody>
</table>
Model Extensions and Experiment

• 2x2 factorial design of the experiment – *in detail*

  – situations KI, KN, LI, LN, based on the extended theoretical model in simplified terms:

  • 2-year-contract instead of 5-year-contract, since the decision problem for AB1 to AB4 is always the same
    → it will only be decided for AB4 and AB5

  • for AB4 and AB5 only 2 possible decisions each are considered, namely: *Invest* (in the sense of pwQR) and *Not invest*;
    too late investment (AB4) is not considered!

  → **Hypotheses** for Investment behaviour of a “real life manager” in each situation…. see next transparency
Model Extensions and Experiment

- Hypothesis ($H_0$); divergent Hypotheses ($H_1$, $H_2$, $H_3$)

<table>
<thead>
<tr>
<th>Investment behaviour for AB4/AB5 in KI KN LI LN</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_0$:</td>
<td>- rational acting (acc.to model)</td>
</tr>
<tr>
<td>I/N I/N I/I I/I</td>
<td></td>
</tr>
<tr>
<td>$H_1$:</td>
<td>- indirect Reciprocity (Nowak, 1998)</td>
</tr>
<tr>
<td>.../I .../N .../I .../N</td>
<td>- Conformity (Bardsley, 2005)</td>
</tr>
<tr>
<td>$H_2$:</td>
<td>- guilt aversion (Charness &amp; Dufwenberg, 2006)</td>
</tr>
<tr>
<td>.../I .../I .../I .../I</td>
<td></td>
</tr>
<tr>
<td>$H_3$:</td>
<td>- forward-induction (Webb, 2007)</td>
</tr>
<tr>
<td>N/N N/N N/N N/N N/N</td>
<td></td>
</tr>
</tbody>
</table>
Thank you for your attention!

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Theoretical Model

- **Proposition 1**: if the profit maximizing $P$ would be the investment decision maker, the direct “right incentives” from WMQR encourage him to invest at a welfare maximizing point in time ($t_{ABn} = n$)

- **Proof** (using the example of AB1):

  - benefits from investing to late in $t_{AB1} = 2$:
    + save depreciation rate
    + get interest profit
    + save penalties from WMQR

  - costs from investing to late in $t_{AB1} = 2$:
    - get penalties from WMQR

  $\rightarrow$ net benefit $< 0 \rightarrow \text{invest in } t_{AB1} = 1$
Theoretical Model

– Reason for not investing in the last year (for AB5)

Benefits from not investing in the last year (year 5):

+ get an additional proportion in the annual profit sharing by interest profits

\[
\int_{4}^{5} f \times 0,25 \min\left(\frac{I_r}{\Pi}, 1\right)e^{-r't} dt
\]
Theoretical Model

• Proposition 2: under WMQR the wage maximizing investment decision maker $A$ who gets from $P$ a standard (real world) labour contract $K$ does \textbf{not invest} at a welfare maximizing point in time in his last year

• Proof:
  – structure of the standard labour contract $K$ means:
    • 5 years
    • fixed salary $f$
    • annual profit sharing up to 25 % from fixed salary

\[
f \times 0.25 \min\left(\frac{\Pi}{\bar{\Pi}}, 1\right)
\]

$\bar{\Pi} = \text{profit goal set by the owner}$

$\Pi = \text{actual profit done by the asset manager}$
Theoretical Model

- **Proposition 3**: under WMQR the investment decision maker $A$ who gets from $P$ an alternative (not real world) labour contract $L$ does invest at a welfare maximizing point in time in his last year.

- **Proof:**
  - alternative labour contract $L$ means:
    - Standard contract $K$ + an annual profit sharing one year after the standard contract ends
    
    $$\int_{5}^{6} f \times 0.25 \min\left(\frac{\Pi}{\Pi},1\right) e^{-rt} dt$$

  - $L$ leads to investing in the last year, because the net benefit $> 0$ compared to not investing.