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# An Actuarial Model of Cross subsidization in Price-Regulated Insurance Markets under Moral Hazard

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## Outline

1. Motivation
2. Literature Review
3. Theoretical Model:
   a. The Compound Aggregate Loss Process
   b. Premium Structure Over Time
      i. Moral Hazard
   c. The Discrete Time Markov Chain
4. Illustrative Examples
5. Conclusion

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# 1. Introduction - Motivation

- Price Regulation ⇔Price Ceiling.
- High Risk (HR) Individuals denied coverage.
- HR enter Assigned Risk Pool (ARP).
- ARP divided among insurers in state (California Auto).
- Low Risk (LR) subsidize HR.
- Cross-subsidization triggers transition of LR individuals into ARP due to inflated premiums.
- Process catalyzed by moral hazard and level of regulated premium (price ceiling).
- Vicious Cycle over time due to Price Regulation.



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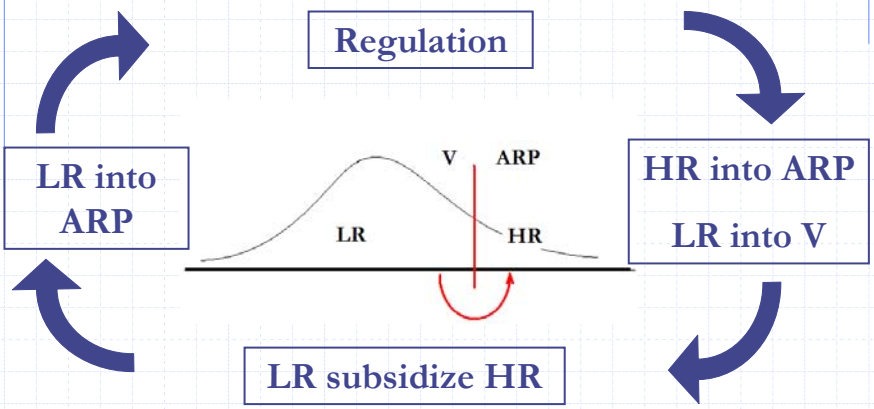
# 1. Introduction - Motivation



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## 2. Literature

- Theoretical Work
  - Taggard (JF, 1981).
  - Doherty & Garven (JF, 1986)
  - Blackmon & Zeckhauser (AER, 1991).
  - Harrington & Niehaus (JFI, 2003).
- Empirical Work
  - Grabowski, Viscusi & Evans (JRI, 1989)
  - Cummins (2002).
  - Harrington (2002).



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## 2a. Aggregate Loss Model

- Random Aggregate Loss Process:

$$S_t = L_{1t} + L_{2t} + ..... + L_{it}, \qquad \begin{matrix} i = 0,1,\ 2,.....m \\ t = 1,\ 2,..... \end{matrix}$$

S = Random Aggregate Loss for year ***t***
L = Random Collective Losses by contract ***i***

- **Assumptions*:***
  - Finite Population
  - No real inflation in claims
  - Discount on Regulated Premium

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# 2a. Aggregate Loss Model

- Compound Density Function:

$$F_S(l) = \sum_{n=0}^{m} p_n \Pr(S \le l | i = n)$$

$$= \sum_{n=0}^{m} p_n F_L^{*n}(l)$$

  - Frequency Probability Mass Function:

$$p_n = \Pr(N = n)$$

  - Severity Density Function:

$$F_L^{*k}(l) = \int_0^l F_L^{*(k-1)}(l-y)\, f_L(y)\, dy$$



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# 2b. Premium Structure

- **Before Price Regulation:**

  All contracts charged their Actuarial Fair Premium (AFP)

- **After Price Regulation - Before Surcharge**:
  - "V" : AFP < $\beta$ where $\beta$ = Price Ceiling
  - "R" : AFP >= $\beta$
  - Premium for contract *i*: $P_{it} = MIN\left[AFP_{i(t-1)}, \beta\right]$
  - Excess loss for contract *i*: $XL_{it} = L_{it} - P_{it}$
  - Total Excess Loss: $TXL_t = \sum_{i=1}^{m} XL_{it}$

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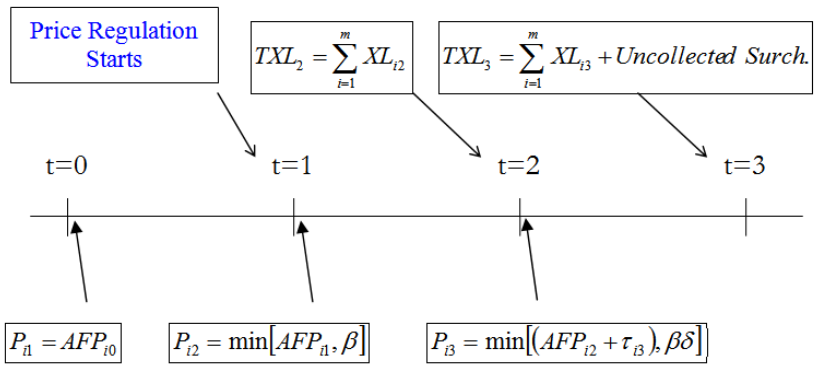
# 2b. Premium Structure

**Premium Structure in a Price-Regulated Industry**




Note: For the voluntary market $AFP_{i1} = AFP_{i2} = AFP_{i3}$.



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# 2b. Premium Structure

- **After Price Regulation - After Surcharge:**
  - Surcharge per contract i: $\tau_{i3} = TXL_2 * w_{i3}$
  - Surcharge weight: $w_{i3} = P_{i2} \Big/ \sum_{i=1}^{m} P_{i2}$
  - Premium for t=2: $P_{i3} = MIN[(AFP_{i2} + \tau_{i3}), \beta]$

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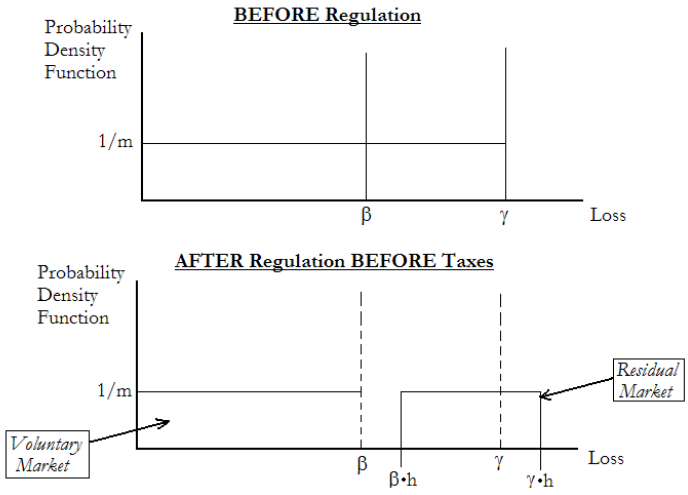
# 2b. Premium Structure

## Moral Hazard Effect



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# 2c. The Discrete Time Markov Chain

- Independent States (V, R)
- Rows in Transition Probability Matrix sum to 1

$$M[t] = [\pi_V^t, \pi_R^t]$$

$$M[t=2]_{1X2} = M[t=1]_{1X2} * \begin{bmatrix} P_{VV}^1 & P_{VR}^1 \\ P_{RV}^1 & P_{RR}^1 \end{bmatrix}_{2X2}$$

- $\pi_i^t$ = Population Proportion in state ***i*** at time ***t***
- $P_{ij}^t$ = Transition Prob. from state ***i*** to ***j*** at time ***t***
- ***Do you see similarities with Credit Risk Classification?***

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## 2c. The Discrete Time Markov Chain

Transition Probability from V to R for contract ***i***:

$$P(R_i|V_i) = P(P_{i3} > \beta\delta)$$

$$= P(P_{i2} + w_{i3} * TXL_2 > \beta\delta)$$

$$= 1 - F_{XL_i}\left(\frac{\beta\delta - P_{i2}}{w_{i3}}\right)$$

← Random Aggregate **Excess** Loss Model



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## 2c. The Discrete Time Markov Chain

**Transition Probability Matrix**

$$= \begin{bmatrix} P^1_{VV} & P^1_{VR} \\ P^1_{RV} & P^1_{RR} \end{bmatrix}_{2\,X\,2}$$

$$= \begin{bmatrix} P^1_{VV} = 1 - P^1_{VR} & P^1_{VR} = 1 - F^k_{XL}\left(\frac{\beta\delta p}{\sum_{i \notin R} P_{i1}} - 1\right) \\ P^1_{RV} = 0 & P^1_{RR} = 1 \end{bmatrix}$$

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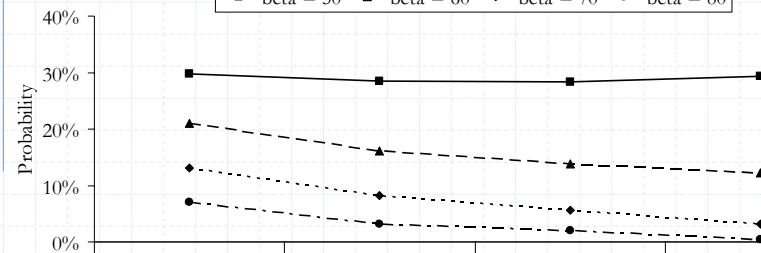
# 3. Illustrative Examples

**Price Ceiling (Beta) on Transition Probabilities**




| | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|
| beta = 50 | 29.78% | 28.49% | 28.30% | 29.40% |
| beta = 60 | 21.07% | 16.16% | 13.85% | 12.24% |
| beta = 70 | 13.08% | 8.21% | 5.60% | 3.22% |
| beta = 80 | 7.06% | 3.19% | 1.96% | 0.41% |

Loss Distribution: **Uniform (0, 100)**



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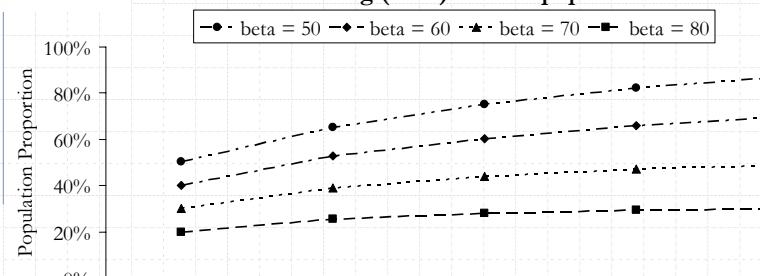
# 3. Illustrative Examples

**Price Ceiling (Beta) on "R" population**




| | Year1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| beta = 50 | 50.3% | 65.1% | 75.1% | 82.1% | 87.4% |
| beta = 60 | 40.1% | 52.7% | 60.4% | 65.9% | 70.0% |
| beta = 70 | 30.0% | 39.1% | 44.1% | 47.3% | 49.0% |
| beta = 80 | 20.0% | 25.6% | 28.0% | 29.4% | 29.7% |

Loss Distribution: **Uniform (0, 100)**

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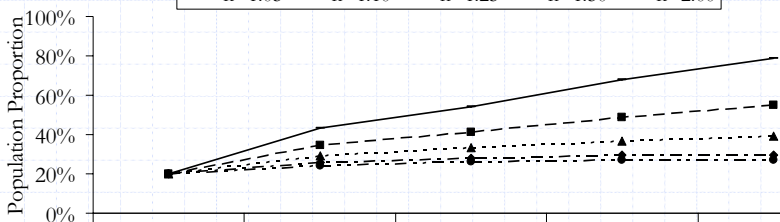
# 3. Illustrative Examples

**Moral Hazard (h) on "R" population**




| | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| h=1.05 | 20.0% | 24.4% | 26.1% | 27.0% | 27.0% |
| h=1.10 | 20.0% | 25.6% | 28.0% | 29.4% | 29.7% |
| h=1.25 | 20.0% | 29.3% | 33.2% | 36.9% | 39.1% |
| h=1.50 | 20.0% | 34.6% | 41.2% | 48.8% | 55.0% |
| h=2.00 | 20.0% | 43.4% | 54.3% | 67.9% | 78.7% |

Loss Distribution: **Uniform (0, 100)**



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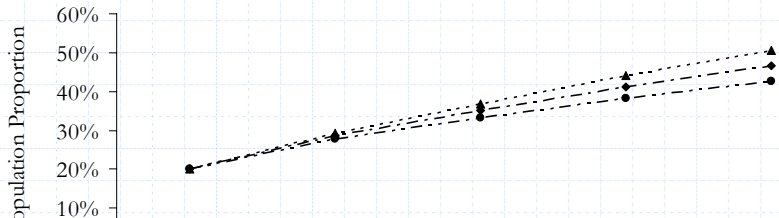
# 3. Illustrative Examples

**Discount (delta) on "R" population**




| | Year1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| delta = 97% | 20% | 28% | 33% | 38% | 43% |
| delta = 96% | 20% | 29% | 35% | 41% | 47% |
| delta = 95% | 20% | 29% | 37% | 44% | 51% |

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## 6. Conclusions

- Moral hazard in the Assigned Risk Pool should be taken into account when price ceilings are set.
- Moral Hazard aggravates cross-subsidization.
- In price regulated systems, the shape of the underlying distribution has to be known and monitored over time.



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