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Adversarial and Non-Adversarial Risk Analysis for Security over Multiples Sites

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SEVENTH FRAMEWORK PROGRAMME

Security Economics: Socio economics meets security

Outline

- Fare evasion
  - Solving only for standard evaders
  - Solving only for colluders
  - Solving both problems simultaneously
- Pickpocketing
- Fare evasion and pickpocketing over multiple stations

General overview

- One station
- Two threats.
  - Fare evasion
  - Pickpocketing by a team.
  - Both threats simultaneously.
- Extension to more than one station.

1. Fare evasion

Description of problem

- Two types of evaders:
  - Standard (standard random process).
  - Colluders (ARA; explicitly modelling intentionality).
- Five countermeasures.
  - Inspectors (preventive/recovery), (x_1, c_1).
  - Security guards (*bouncers*), usually outsourced (preventive), (x_2, c_2).
  - Guards, working solo or in pairs (preventive/recovery), (x_3, c_3).
  - Automatic access doors (preventive), $(x_4 \leq n_4, c_4)$.
  - Metro officers (preventive), $(x_5,$ negotiation$)$.
- In general, the more resources, the less fare evasion will be. Also, the more inspectors, the more customers checked and, possibly, the more fines collected.

Three types of customers

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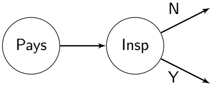
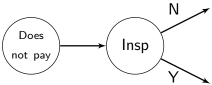
1. Civic customers.



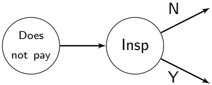
+ Metro	− Metro
Ticket	
Ticket	Annoyed customer

2. Standard fare evaders.



+ Metro	− Metro
	Ticket
Fine	

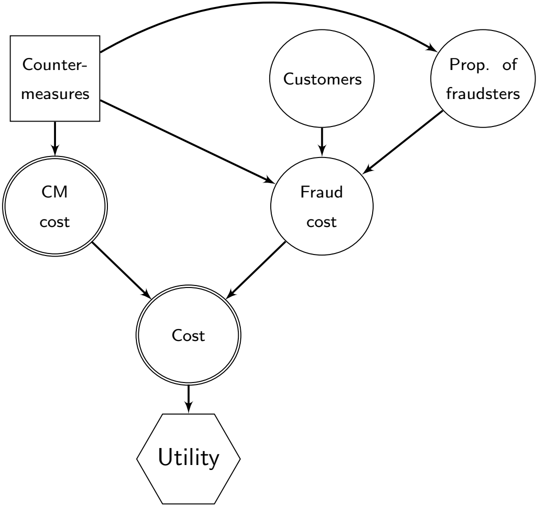
3. Colluding fare evaders.



+ Metro	− Metro	+ Customer	− Customer
	Ticket	Ticket	Cost
Fine			Cost, fine

Solving only for standard evaders

- This is a 'standard' risk management problem



Solving only for standard evaders (cont.)

- Operator invests $c_1x_1 + c_2x_2 + c_3x_3 + c_4x_4 + x_5$. (Constraints)
- $p(x)$ proportion of standard evaders. $q(x_1)$ proportion of customers inspected.
  - $1 - p(x) \longrightarrow N_1$ civic customers pay ticket.
  - $p(x)[1 - q(x_1)] \longrightarrow N_2$ not pay ticket, not caught (loss t).
  - $p(x)q(x_1) \longrightarrow N_3$ do not pay ticket but are caught (income f).

$$c_D(N_1, N_2, N_3) = 0 \times N_1 - t \times N_2 + f \times N_3 - \sum_{i=1}^{4} c_4x_4 - x_5.$$

- Evaluate security plan x maximising expected utility

$$\max_{x \in \mathscr{B}_1} \psi(x) = \sum_{N_1,N_2,N_3} u_D(c_D(N_1, N_2, N_3))p^1_{N_1x}\, p^2_{N_2x}\, p^3_{N_3x}.$$

Typical assumptions

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$$N_1 \sim \mathscr{P}ois\,(\lambda_1 = N[1-p(x)])$$
$$N_2 \sim \mathscr{P}ois\,(\lambda_2 = Np(x)[1-q(x_1)])$$
$$N_3 \sim \mathscr{P}ois\,(\lambda_3 = Np(x)q(x_1))$$

- Each additional inspector inspects fraction ρ of tickets

$$q\,(x_1) = \rho x_1\,.$$

- Each additional measure has a (dampened) deterrent effect

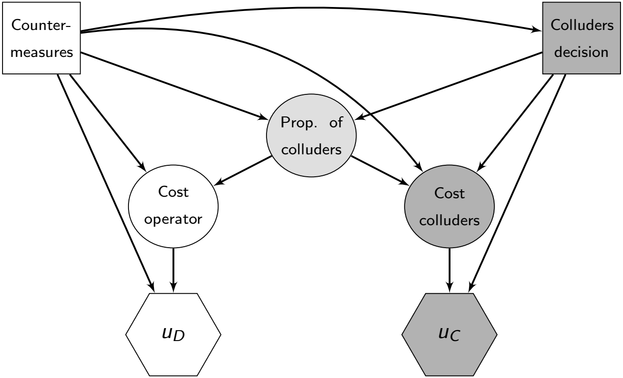
$$p\,(x) = p(x_1, x_2, x_3, x_4, x_5) = p_0 \exp(-\gamma_1 x_1 - \gamma_2 x_2 - \gamma_3 x_3 - \gamma_4 x_4 - \gamma_5) + p_r\,.$$

- u_D risk averse, u_D strategically equivalent to

$$u_D(c_D) = -\exp(-k_D c_D),\ k_D > 0.$$

Solving only for colluders

- This is an adversarial problem



Colluders dynamics

- "Club" entailing M operations over incumbent planning period.
  - They see security investments x (Sequential Defend-Attack).
  - They decide proportion r of fare evasion
  - Actual proportion r' depends also on $(x_1, x_2, x_3, x_4, x_5)$.
  - Operational costs, including preparation costs c_e

$$c = t(M_2 - M_1) - fM_3 - rc_e M.$$

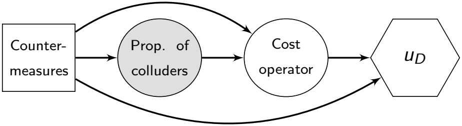
    - M_1 evaders pay (abortion).
    - M_2 not pay, not caught.
    - M_3 not pay, caught.

$$(M_1, M_2, M_3) \sim \mathscr{M}\left(M; (1-r'), r'(1-q_A(x_1)), r' q_A(x_1)\right).$$

  - Their utility (risk prone)

$$u_C(c - rc_e M).$$

Operator's problem



- Relevant revenues and costs

Concept	Revenue
Security costs	$-(c_1x_1 + c_2x_2 + c_3x_3 + c_4x_4 + x_5)$
Tickets lost	$-tM_2$
Fines won	fM_3

- Total increase in outcome is

$$c_D = fM_3 - tM_2 - (c_1x_1 + c_2x_2 + c_3x_3 + c_4x_4 + x_5).$$

Operator's problem (cont.)

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- $u_D \longrightarrow$ utility, $h(r|x)$ models their beliefs over r given x, then

$$\psi(x) = \int \left[\sum_{M_1, M_2, M_3} p_{M_1 M_2 M_3 x}\, u_D \left(fM_3 - tM_2 - \sum_{i=1}^{4} c_i x_i - x_5 \right) \right] \times h(r|x) dr,$$

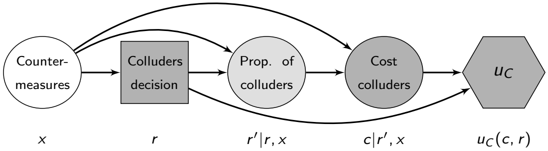
$p_{M_1 M_2 M_3 x} = \Pr(M_i \text{ type } i \text{ colluders} | x \text{ invested}),\ \sum_{i=1}^{3} M_i = M.$

- They must solve

$$\max_{x \in \mathscr{B}_1} \psi(x_1, x_2, x_3, x_4, x_5),$$

but $h(r|x)$ not directly available ($\longrightarrow$ Attacker's problem).

Attacker's problem



- x, security investment by Operator. We may consider $p_A(x)$ (Attacker's beliefs over x), although not necessary (is seen).
- r, decision made by Attacker.
- r', effective fare evasion proportion.
  - One possible model $r' = r(1 - s(x_1))$, $s(x_1)$ proportion of evasion abortions.
  - $p_A(s(x_1)) = p_A(s|x_1)$ induces $p_A(r'|r, x)$.
- c, global costs of evasion operation.
- u_C, utility over consequences $u_C(c - rc_e M)$.

Solving Attacker's problem

1. Integrate out uncertainty over c, getting expected utility

$$\psi_A(r', r, x) = \int \left[\sum_{M_1, M_2, M_3} p_{M_1 M_2 M_3 x} \right.$$

$$\left. \times \; u_C\left(t(M_2 - M_1) - fM_3 - rc_e M\right) \right] \times g_A(q_A | x_1) dq_A.$$

   $g_A(q_A|x_1)$ density over $q_A|x_1$, inducing $p_A(c|r', x)$.

2. Integrate out uncertainty over r', obtaining expected utility

$$\psi_A(r, x) = \int \psi_A(r', r, x) p_A(s|x_1) ds.$$

3. Find Attacker's optimal strategy

$$r(x) = \arg\max_r \psi_A(r, x).$$

Simulation scheme for estimating $h(r|x)$

- Uncertainty about $u_C(\cdot)$, $g_A(q_A|\cdot)$, $p_A(s|\cdot)$, modelled through $U_C(\cdot)$, $G_A(q_A|\cdot)$, $P_A(s|\cdot)$, has to be propagated.

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For each x
  For i = 1 to K
    Sample U_C^i, G_A^i(q_A|·), P_A^i(s|·). Compute
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$$\psi_A^i(r',r,x) =$$

$$\int \left[\sum_{M_1,M_2,M_3} p_{M_1M_2M_3x} U_C^i\left(t(M_2 - M_1) - fM_3 - rc_eM\right) \times G_A^i(q_A|x_1) \right] dq_A.$$

Compute

$$\psi_A^i(r,x) = \int \psi_A^i(r',r,x) P_A^i(s|x_1) ds.$$

Compute random optimal alternative

$$R^i = \arg\max_r \psi_A^i(r,x).$$

Approximate $p_A(R(x) \leq r) \approx \#\{1 \leq i \leq K : R^i \leq r\}/K$.

Typical assumptions

- Colluders risk prone in benefits $\longrightarrow u_C$ strategically equivalent

$$u_C(c) = \exp(k_C c),\ k_C > 0.$$

  - A random utility model could be

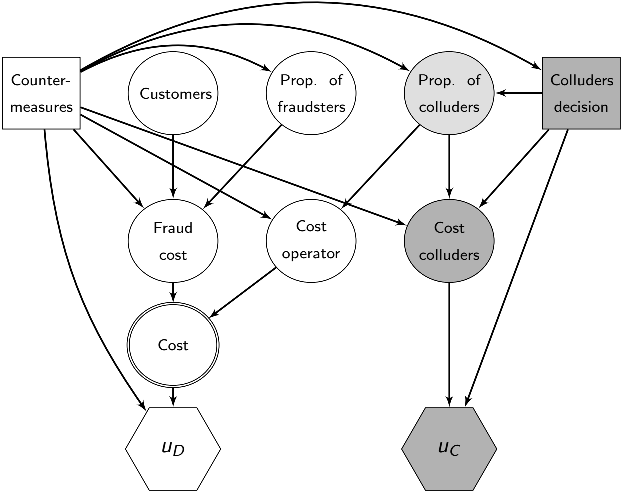
$$U_C(c) = \exp(k_C c),\ k_C \sim \mathscr{U}(0, K_C).$$

- Evaders proportion $s \sim \mathscr{B}e(\alpha, \beta)$. Dirichlet process with base $\mathscr{B}e(\alpha, \beta)$ for P_A

$$P_A \sim \mathscr{D}\mathscr{P}(\mathscr{B}e(\alpha, \beta), \delta_1).$$

  - If we consider $r' > r$, we could use an error model $r' = r + s$, s described by $p_A(s)$ and $P_A \sim \mathscr{D}\mathscr{P}(p_A, \delta_2)$.
- Proportion of inspections $q_A(x_1) \sim \mathscr{B}e(\alpha, \beta)$ with $\frac{\alpha}{\alpha+\beta} = \delta x_1$ and small variance.
  - Then, $G_A \sim \mathscr{D}\mathscr{P}(\mathscr{B}e(\alpha, \beta), \delta_3)$.

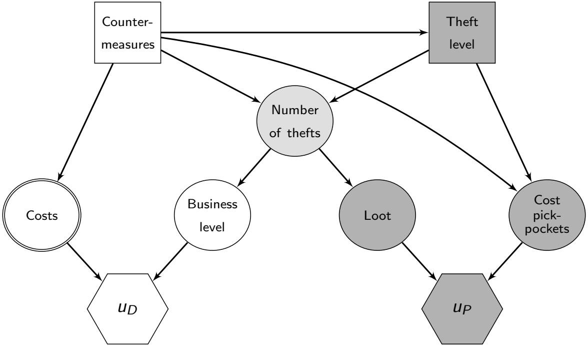
Solving the problem when both evaders are present



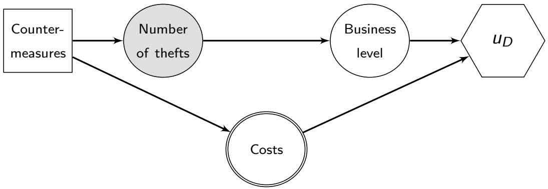
2. Pickpocketing

Description of problem

- Four countermeasures.
  - Patrols (preventive/recovery), (y_1, d_1).
  - Cameras (preventive), (y_2, d_2).
  - Guards (preventive/recovery), (x_3, c_3).
  - Public awareness plans (preventive), (y_3).



Defender's problem



- Operator invests y_1, y_2, x_3 (units) and y_3 (in the plan).
- Faces a delinquency level.
- Sees a decrease in business.
- Gets her utility (depends on business level and operator costs).

Defender's problem (cont.)

- Security costs

$$c'_D(y_1, y_2, x_3, y_3) = d_1 y_1 + d_2 y_2 + c_3 x_3 + y_3.$$

- b, business level, T theft level, $u_D(c'_D, b)$ Defender's utility

$$\max_{y \in \mathscr{B}_2} \iint u_D(c'_D, b) p(b|T) p(T|y) \, \mathrm{d}T \, \mathrm{d}y.$$

- $u_D(c'_D, b)$ includes costs and reduction in business level

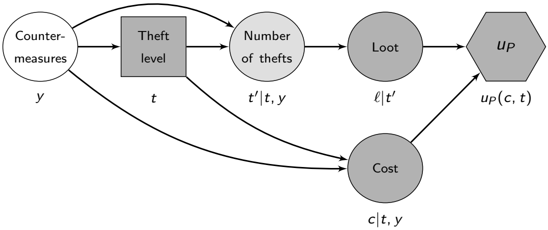
$$c'_D + (b_0 - b).$$

- Operator typically risk averse with respect to costs

$$u_D(c'_D, b) = -\exp\left(k'_D \cdot [c'_D + (b_0 - b)]\right), \; k'_D > 0.$$

- To assess $p(T|y) \longrightarrow$ Attacker's problem.

Attacker's problem



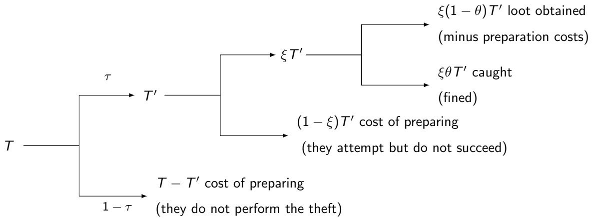
- See Defender's investment (y_1, y_2, x_3, y_3).
- Decide on target theft level T.
- Implement actual number of theft operations, $T' = \tau T$.
- Costs (of implementing) their actions is $c_p T$.

Attacker's problem (cont.)

- Face operational costs.
  - With prob. $(1-\xi)$, unsuccessful attempt. No consequences.
  - With prob. $\xi\theta$, succeed but caught. Fine g.
  - With prob. $\xi(1-\theta)$, succeed and not caught. Loot L.
- Total cost/benefit balance

$$c = \left[-c_p \times T_1\right] - \left[(g+c_p)\times T_2\right] + \left[(L-c_p)\times T_3\right] = -c_p T - g T_2 + L T_3.$$

- Get utility $u_P(-c_p T - g T_2 + L T_3)$.



Solving Attacker's problem

For each y
  For i = 1 to K
    Sample $U_P^i, P_A^i(\tau|\cdot), P_A^i(\xi|\cdot), P_A^i(\theta|\cdot)$.
    Compute

$$\psi_P^i(t', t, y) = \iint \left[\sum_{T_1, T_2, T_3} p_{T_1 T_2 T_3 y} \int U_P^i\left(-c_p T - g T_2 + L T_3\right) dU_P \right] \times P_A^i(\xi | y_1, x_3, y_3) P_A^i(\theta | y_1, x_3) d\xi d\theta.$$

    Compute

$$\psi_P^i = \int \psi_P^i(t', t, y) P_A^i(\tau | y_1, x_3) d\tau.$$

    Compute (and register) the optimal alternative

$$T^i = \text{argmax}_t \; \psi_P^i(t, y).$$

  Approximate $p_A(T(y) \leq t) \approx \#\{1 \leq i \leq K : T^i \leq t\}/K$.

Model assumptions and uncertainties

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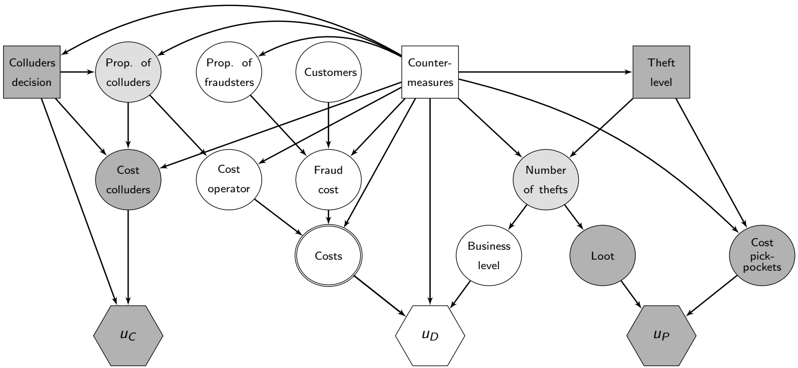
- $\ell \sim \mathscr{U}(\ell_a, \ell_b)$, loot obtained when:
  - t', effective theft level $t' = t\tau(y_1, x_3)$.
    - $p_A(\tau(y_1, x_3)) = p_A(\tau | y_1, x_3)$ induces $p_A(t' | t, y)$.
  - ξ, success rate
    $\xi(y_1, x_3, y_3) = \xi_0 \exp(-\mu_1 y_1 - \mu_2 x_3 - \mu_3 y_3) + \xi_r$.
    - $p_A(\xi(y_1, x_3, y_3)) = p_A(\xi | y_1, x_3, y_3)$ induces $p_A(\ell | t')$.
  - θ, detention rate $\theta(y_1, x_3) = \rho_1 y_1 + \rho_2 x_3$.
    - $p_A(\theta(y_1, x_3)) = p_A(\theta | y_1, x_3)$ induces $p_A(c | t, y)$.
- $u_P(c) = \exp(k_P c)$, $k_P > 0$, $U_P(c) = \exp(k_P c)$, $k_P \sim \mathscr{U}(0, K_P)$.

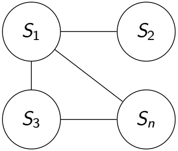
3. Fare evasion and pickpocketing over multiple stations

Joint influence diagram



Multiple sites problem

- Colluders and pickpockets do not make common cause.
- We can solve their problems separately.
- A network of n interconnected stations



- For each station a model like above is applicable, with mobile resources subject to global and specific budget and mobility constraints.

Mobility rules

- Fare evaders
  - If too many security measures in entering station i, move to adjacent station i'.
  - If inspectors in intermediate station k, an alternative route.
- Pickpockets
  - If too many security measures in station i, move to adjacent station i'.
- Some personnel (inspectors, patrols, guards) are mobile.

Main results

- A DSS is being currently devised to help decision makers.
- Upon perceived low-level threats, authorities tend to underestimate risk.
  - Attackers see a breach in security (more attackers).
  - Great impact can be caused even with low-profile attacks.
  - Low-cost preventive measures and well-trained personnel could deter attackers or minimize their number.
- Under scenario of high probability of attack.
  - Authorities tend to invest on expensive (sometimes sensationalist and ineffective) measures.
  - Set up security and mobility protocols for personnel increase their efficiency.

Conclusions

- For fare evasion, a mixed non adversarial - adversarial problem has been tackled.
- For pickpockets, not only direct economic impact considered (also image costs).
- General model over multiple sites has been devised.
  - Resources are constrained by budget and mobility.
  - Some countermeasures have to be shared for both threats.