Simulating Collusion
Challenging Conventional Estimation Methods

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Tip of the Iceberg

OECD Survey (2022)

"...the amount of commerce affected by just 16 large cartel cases [...] exceeding USD 55 billion world-wide."

Prior Work: Estimate the probability of death

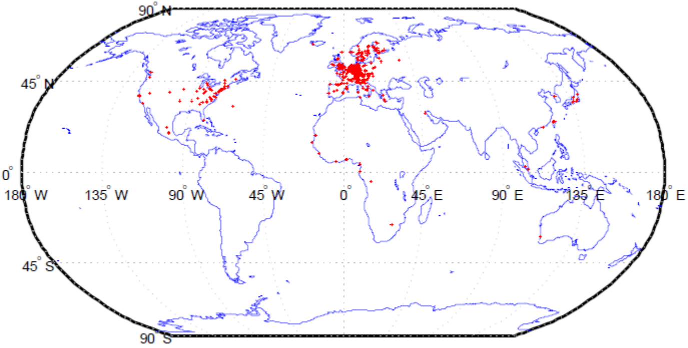
Hazard Rate and Capture Recapture

- Bryant & Eckard (1991): 5-7 years average duration, 13-17% probability of detection per year (US cartels)
- Combe, Monnier & Legal (2008): 7.46-7.8 years average duration, 12.9-13.3% probability of detection per year (EU cartels)
- Levenstein & Suslow (2011): 8.1 years average duration (US and EU cartels)
- Ormosi (2014): 10-20 % probability of detection per year (EU cartels)

Strict Assumptions

- Detected sample is random
- Collusion is (i) independent and (ii) constant over time
- Detection of collusion is (i) independent and (ii) constant over time

Potential Selection: EU Sample



Cartels detected by European Commission: 1957-2010 (v. Babo (2013))

- China: largest exporter, originally dominated by state monopolies
- South America: homogeneous product oligopoly markets

Does the data fit the model?

Research Question

Do conventional methods correctly estimate the probability of death, being caught and explain duration?

Structure of the Study

1. Simulate models of collusion (data generating process (dgp))
2. Generate population of collusion
3. Retrieve sample of detected cartels
4. Test Conventional Methods HR, CR, probit etc. on population and sample

Simulating Theoretical Models (II)

Simulation: Variables and Theory

Variable		Values	Theory
Number of Firms	n_{firms}	$\{2, 3, .., 10\}$	Stigler (1964)
Detection Probability	ρ	$\{0.1,..,0.35\}$	Bos et al. (2018)
Constant (0), Increasing (1)	*structured*	$\{0,1\}$	Chang et al. (2009)
Fine (% of Profit)	γ	$\{0.7, 0.8, 0.9\}$	Bos and Schinkel (2006)
Leniency (% of Fine)	θ	$\{0,0.5,1\}$	Bos et al. (2018)

Simulating Theoretical Models (I)

Incentive Compatibility Constraints (ICC): $\pi_i^c/(1-\delta) \geq \pi_i^d + \delta\pi_i^n/(1-\delta)$

I. Model I (Stigler (1964)): No enforcement, ICC entry = ICC exit: $\delta \geq 1 - 1/n$

II. Model IIa and IIb (Bos et.al. (2018)): Constant detection probability
ICC entry: $\delta \geq (n+\rho\gamma-1)/(n+\rho\gamma-\rho)$
ICC exit: $\delta \geq (n+\rho\gamma-1-\theta\rho\gamma)/(n+\rho\gamma-\rho-\theta\rho\gamma)$,
with $\theta = 0$ being full immunity from fines (Model IIb)

III. Model IIIa and IIIb (Chang and Harrington (2009)): Increasing detection probability
$\rho_{new} = \rho + \rho/2^{nTC}$

Simulating Patience (δ)

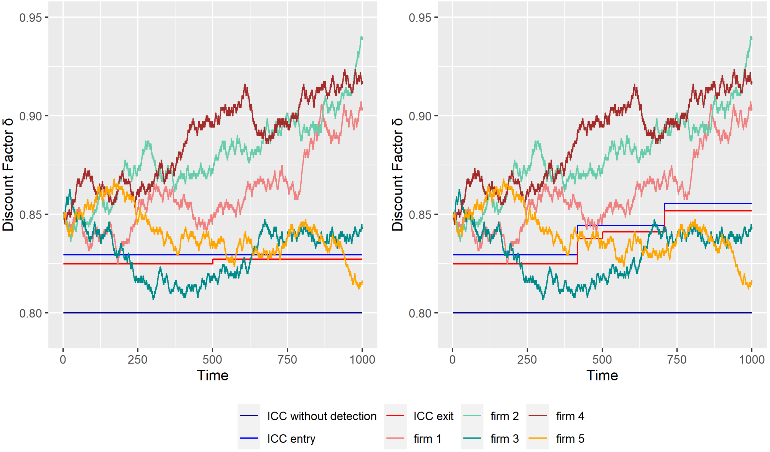
- Firm specific patience is

$$\delta_{firms} = 1/1 + r,$$

- with r the real interest rate[1]
- Harrington (1989) varying discount factors to imperfect capital market information or principal-agent-problem
- Modeling other aspects of the model stochastically might be of interest
  - δ itself
  - Demand and cost shocks
  - Martin (1988) and Motta (2004)

[1] For the random walk let $X_1 = 0$ with $p(X_{t+1} = X_t + 1) = 0.5$ and $p(X_{t+1} = X_t - 1) = 0.5$. Then $r_{t+1} = f(X_t) = (2 * X - 1)/100$ and $\delta_t = g(r_t) = atan(2 * 1/(1 + r))/\pi + 0.5$.

Model II and III - Simulated Patience and ICC

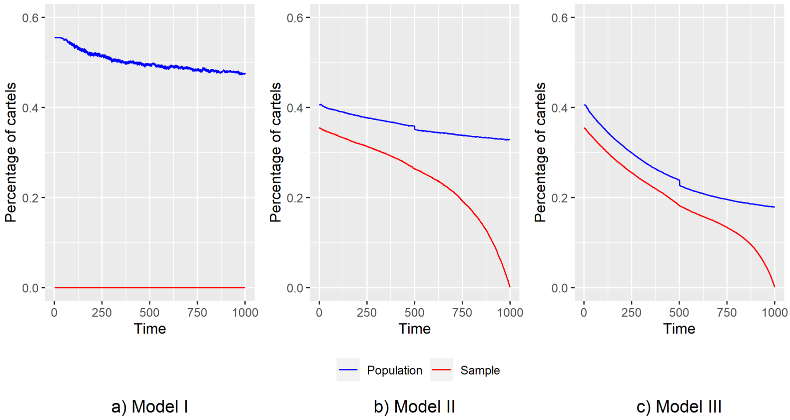


a) Model IIa,b

b) Model IIIa,b

Model II and III ($n_{firms} = 5$), detection probability starting with ($\rho = 15\%$)

Simulated Cartels



(a) No Enforcement (b) Constant Detection Probability (c) Increasing Detection Probability

Mean Duration and Probability of Death (Bryant & Eckard (1991))

	Average Arrival θ^{-1}	Births θ	Average Duration λ^{-1}	Deaths λ	Alive θ/λ	Obserations N
Model I						
All Cases (Population)	0.140	7.12	190.76	0.005	1'359	7'122
Model IIa,b						
Detected Cases (Sample)	0.005	220.92	160.83	0.006	35'532	220'923
Undetected Cases (Population - Sample)	0.007	153.36	109.45	0.009	16'786	153'357
All Cases (Population)	0.003	374.28	139.78	0.007	52'317	374'280
Model IIIa,b						
Detected Cases (Sample)	0.005	213.09	130.68	0.008	27'845	213'086
Undetected Cases (Population - Sample)	0.008	123.25	71.79	0.014	8'847	123'246
All Cases (Population)	0.003	336.33	109.10	0.009	36'693	336'332

$\theta^{-1} = timespan/N$

$\lambda^{-1} = \sum duration/N$

The most basic model is

$$\lambda(t) = \lim_{dt \to 0} \frac{Pr(t \leq T < t + dt | T \geq t)}{dt} = \frac{f(t)}{S(t)} = -\frac{S'(t)}{S(t)}$$

where t represents time and S is the hazard function. The hazard function can also be represented as a cumulative hazard function $\Lambda(t) = -\log S(t)$.

Hazard Rate 95% Confidence Intervals

Hazard Rate 95% Confidence Intervals

	Population		Sample	
	CI - Start	CI - End	CI - Start	CI - End
n_{firms}	0.366	0.371	0.034	0.040
Fines (γ)	-0.116	-0.056	-0.169	-0.096
Leniency (θ)	-0.681	-0.664	-0.007	0.014
Start Leniency ($t > 500$)	-0.502	-0.487	-0.311	-0.295
structured	0.394	0.404	0.264	0.277
Detection prob. (ρ)	3.404	3.471	3.047	3.126
Constant	-4.786	-4.725	-5.636	-5.560

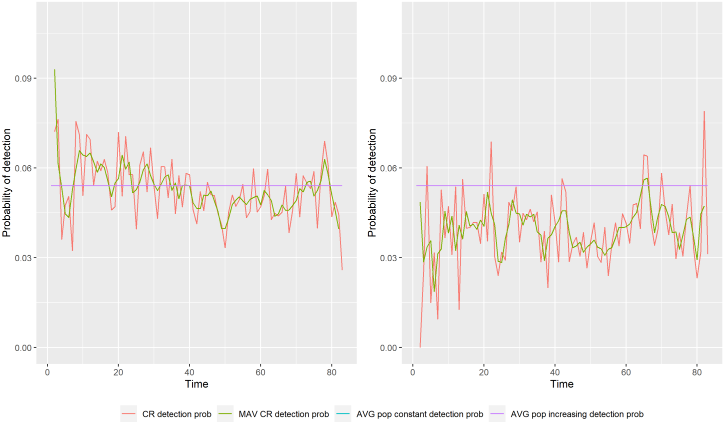
Capture Recapture (Ormosi 2014)

- Estimate capture, survival rates and size of animal populations (Amstrup, Manly and Mcdonald (2010) and McCrea and Morgan (2015)

$$n = \frac{mc}{r},$$

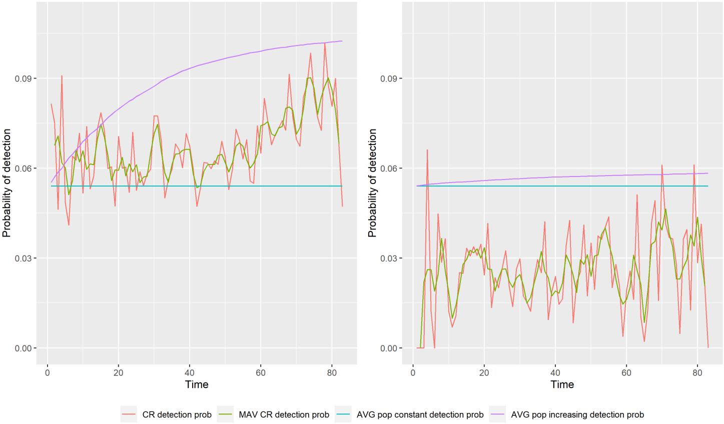
  where n represents the population size, m the number of captured and marked animals, c the total number of captures during the second visit and r the number of recaptures on the second visit.
- Pre-specified area, part of an animal population is captured, marked, and released over time. Afterward, another portion is captured in exactly the same area and the number of marked individuals within the sample is counted.
- Likelihood specification with limited capability for modeling heterogeneity
- Probability of survival or detection can change after a capture
- Survival rate is constant over time except in the year following detection
- Probability of detection is time dependent and varies every year

Capture Recapture: Constant Detection (Model II)



Model II (constant ρ): CR Estimated Detection Probability with (a) Few Firms (b) Many Firms

Capture Recapture: Increasing Detection (Model III)



Model III (increasing ρ): CR Estimated Detection Probability with
(a) Few Firms (b) Many Firms

Conclusion and Future Research

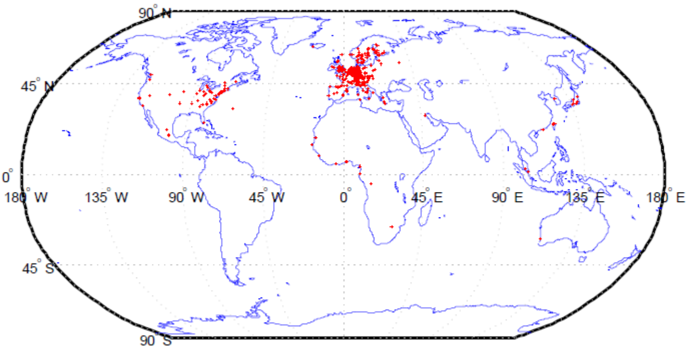
Findings

- Estimators differ between population and sample
- Duration, probability of death and caught
- For hazard, capture recapture

Future Research

- Probability of being Caught
- Probit
- Heckmann selection
- Miller (2006)
- Hyytinen (2018)

Addressing Selection



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