A Common Pool Resource Experiment with a Dynamic Stock Externality

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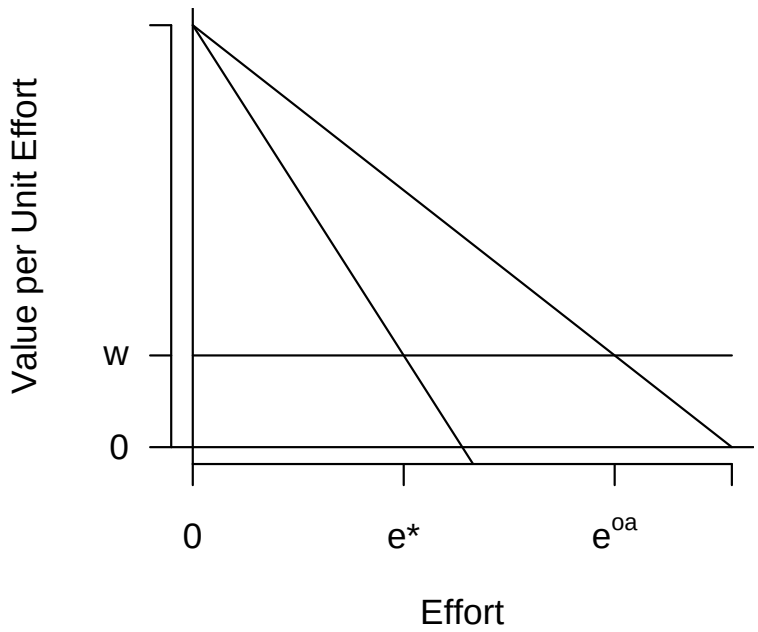
Open Access Management of a Common Pool Resource

- Common Pool Resource An economic resource that is *subtractable* and *non-excludable* (*alias* Common Property)
- Open Access A management regime in which multiple individuals have essentially unlimited right of use.
- Prediction Open Access Management of a CPR will lead to overuse.
- Two methods of modelling
  - static externality
  - dynamic externality

Research Agenda

- Static model has been studied extensively (Ostrom, Walker, Gardner)
  - Without communication, Nash equilibrium (close to open access) prevails.
  - Non-binding Communication reduces effort, increases surplus
- Dynamic Models have received very little attention
- This project: A systematic comparison of communication in static and dynamic environments.

Static CPR (Gordon, 1954)



Yield-Effort Curve

$$y = ae - be^2, \quad a, b > 0$$

Industry Profits

$$\begin{aligned} \pi &= py - we \\ &= p(ae - be^2) - we \end{aligned}$$

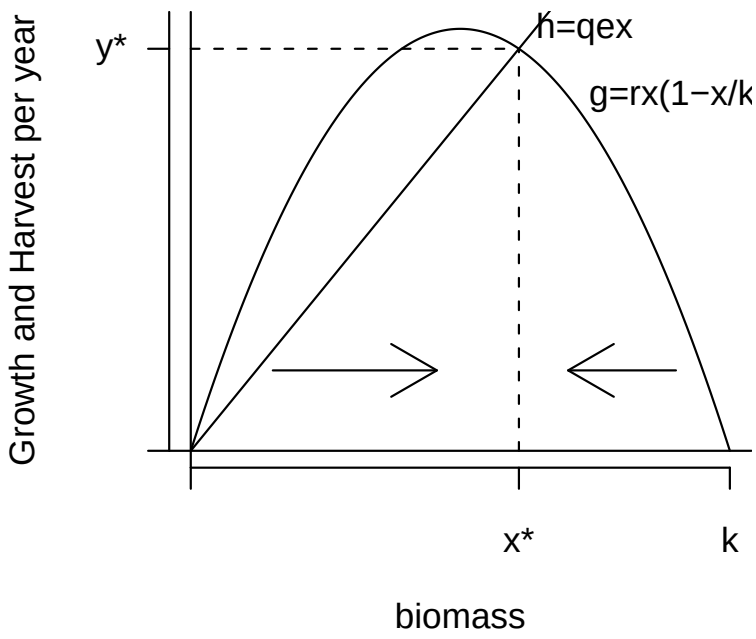
Efficient Effort

$$e^* = \frac{a - w/p}{2b}$$

Open Access Effort

$$e^{oa} = \frac{a - w/p}{b}$$

Dynamic Biological Model (Schaefer, 1957)



Natural Growth

$$g = rx(1 - \frac{x}{k})$$

Harvest

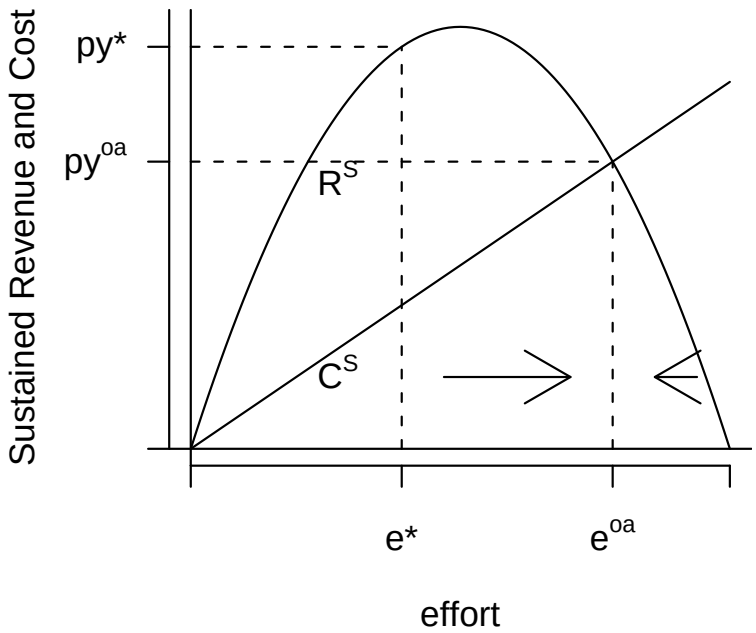
$$h = qex$$

Change in Stock

$$\dot{x} = g - h$$
$$= rx(1 - \frac{x}{k}) - qex$$

For any sustained level of effort, biomass and yield converge to sustained values.

Dynamic CPR (Munro, 1982)



Profit

$$\pi = pqex - we$$

Entry

$$\dot{e} = \mu\pi$$

Static model is the steady state of the dynamic model.

Correspondence

$$a = qk$$

$$b = q^2 k/r$$

Laboratory Environment

- Groups of 8 subjects, fixed within session
- Decision Context
  - Subjects represent villagers
  - Each decision period represents month of 25 days
  - Subjects allocate days between fishing and farming
  - Farming returns 5 L$ per day
  - Fishing returns proportionate share of catch
- Z-Tree Implementation with Payoff Calculator
- Static or Dynamic Environment (next slide!)
- Communication Option
  - Ater every four periods
  - Subjects stand at stations, discuss reponse, make private decision
- Communication Structure
  P P P D D D D (C) D D D D (C) ... (C) D D D D

Static Environment

- Harvest Function

$$h = \max(ae - be^2, 0)$$

- Individual Payoff

$$\pi_j = w(d - e_j) + p\frac{e_j}{e}(\max(ae - be^2, 0))$$

- Efficient (Optimal) Effort

$$\sum_{j=1}^{J} e_j^* = \frac{a - w/p}{2b}$$

- Nash Equilibrium Effort

$$e_j^N = \frac{1}{J+1}\frac{a - w/p}{b}$$

- Open Access Equilibrium Effort

$$e_j^{oa} = (a - w/p)/b \quad \forall j$$

Dynamic Environment

- Harvest Equation

$$h_t = qe_t x_t$$

- Stock Equation

$$\begin{aligned} x_{t+1} &= x_t + g_t - h_t \\ &= x_t + rx_t\left(1 - \frac{x_t}{k}\right) - qe_t x_t \end{aligned}$$

- Individual Payoff

$$\pi_{jt} = w(d - e_j) + pqe_{jt}x_t = \pi_{jt}(x_t, e_{jt})$$

- Steady state benchmarks computed using same formulas as the Static Model
- Dynamic Efficiency Benchmark computed by Dynamic Programming

Parameters

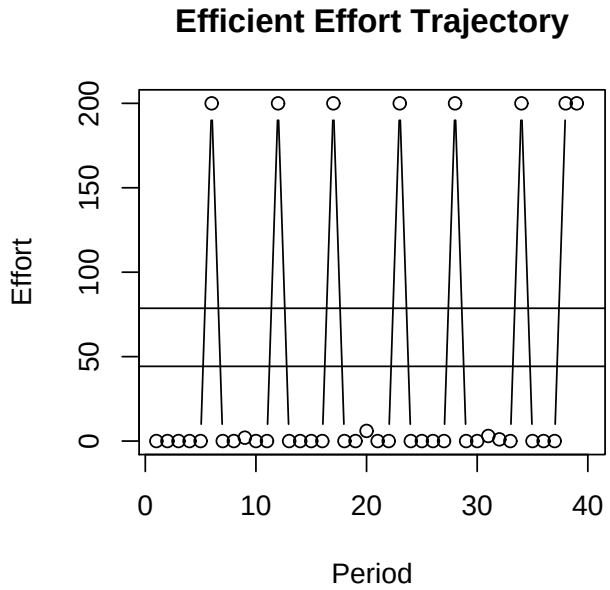
symbol	item	static	dynamic
d	endowment of effort per month	25	25
p	price of fish	1	1
w	opportunity cost of effort	5	5
a	linear coefficient in harvest function	23	23
b	quadratic coefficient in harvest function	0.25	0.2035
k	carrying capacity of fishery		10000
q	catchability coefficient		0.0023
r	unconstrained growth rate		0.26

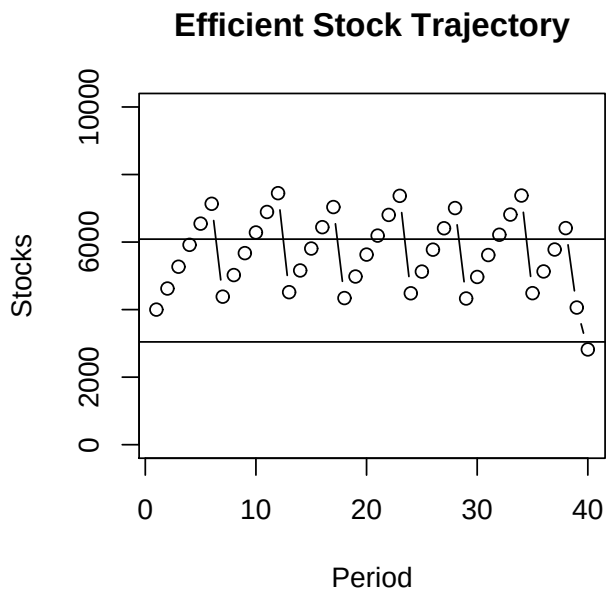
Benchmarks

Comparative Benchmarks Assuming the Steady State of the Dynamic Model.

symbol	item	static	dynamic
e^*	socially optimal aggregate effort	36	44
e^N	Nash equilibrium aggregate effort	64	79
e^{oa}	Open Access equilibrium effort	72	88
x^*	Socially optimal stock		6175
x^N	Nash equilibrium stock		3043
x^{oa}	Open Access equilibrium stock		2174
π^*	Total Payoff at Social Optimum	1324	1407
π^N	Total Payoff at Nash Equilibrium	1068	1147
π^{oa}	Total Payoff at Open Access	1000	1000

Efficient Trajectories for Effort and Stock





Optimal Value of Dynamic Games

No. of Periods	Efficient Payoff	
	Total	per Period
10	12,160	1316
16	21,713	1357
20	27,392	1370
40	55,866	1397

Experimental Design

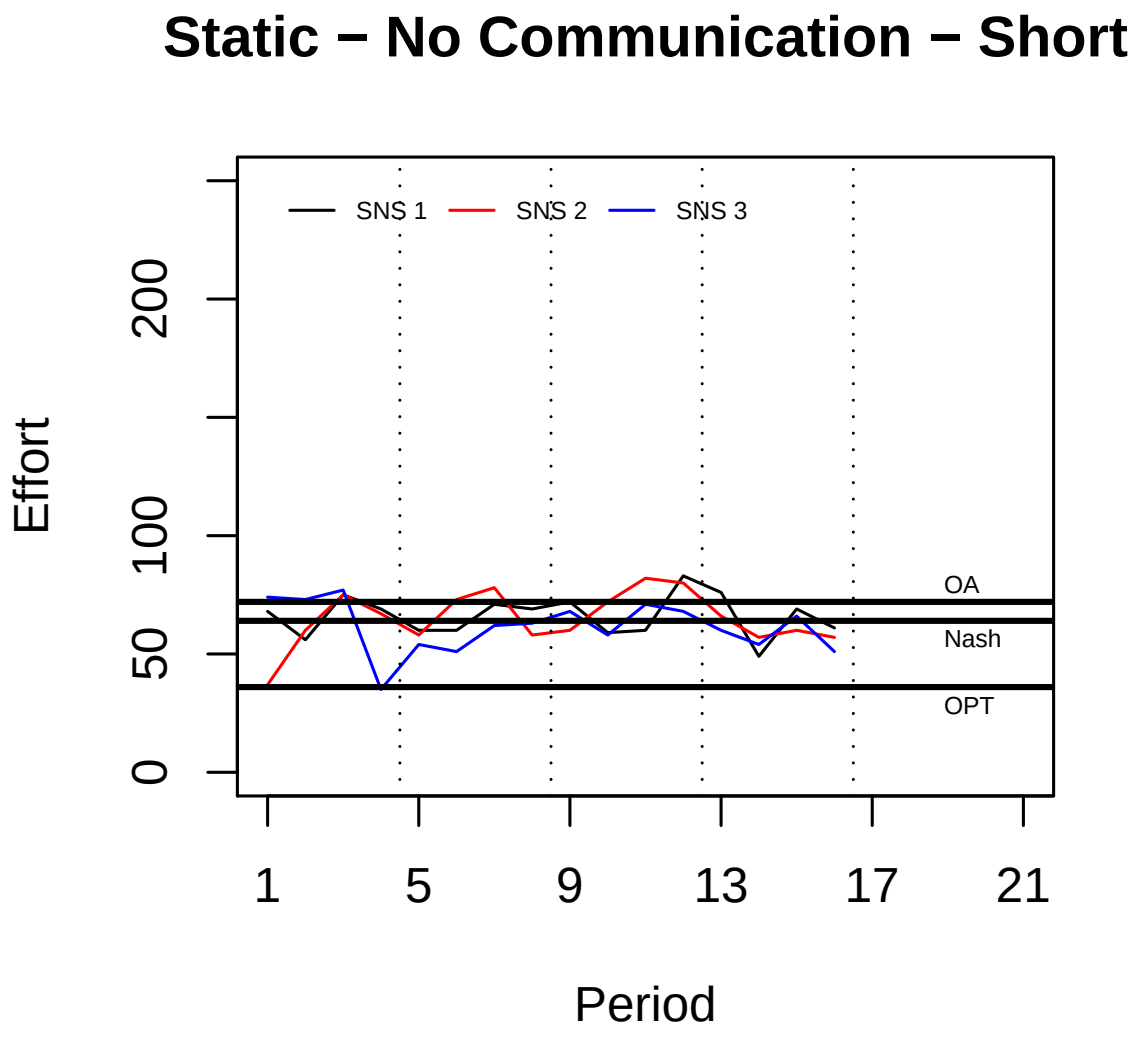
Number of Sessions by Treatment

		Communication?	
Specification	Length	No	Yes
Static			
	Short	3	3
Dynamic			
	Short	3	3
	Long		3

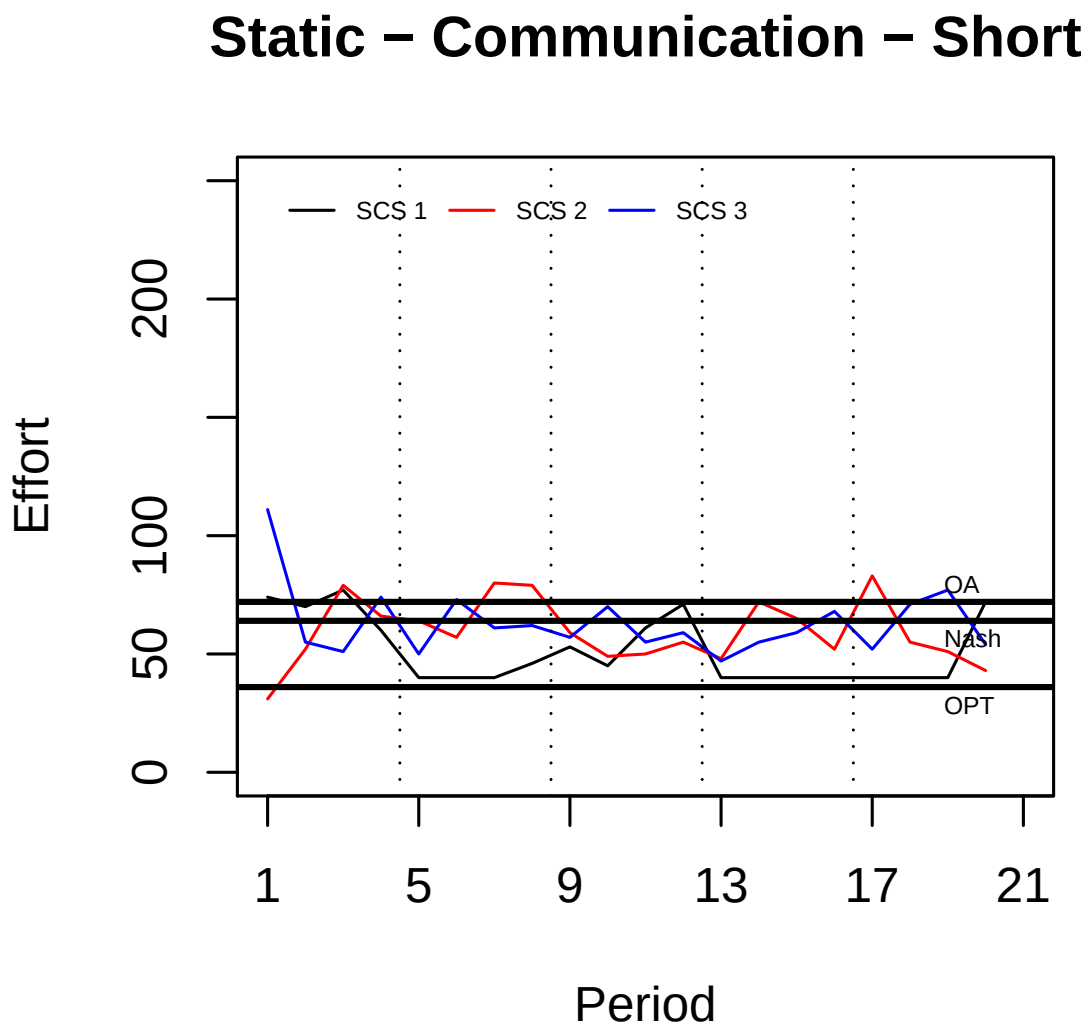
Hypotheses and Expectations

- Exploratory Work - Hypotheses are informal
- Static No Communication Sessions should converge to Nash
- Cheap talk should reduce effort in static model
- Dynamic No-Communication should converge to open access
- Coordination should be more difficult in dynamic environments:

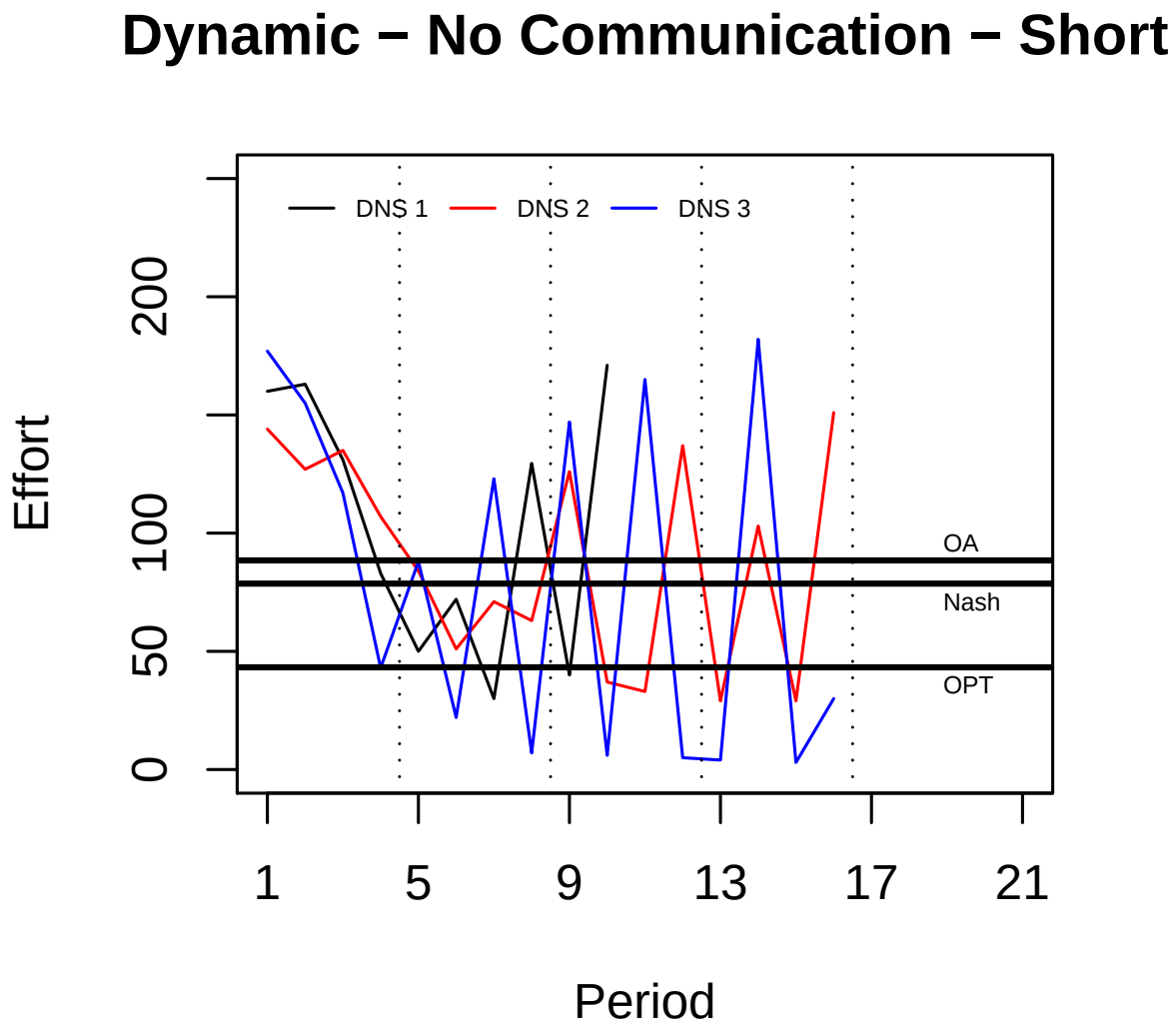
Static, No Communication



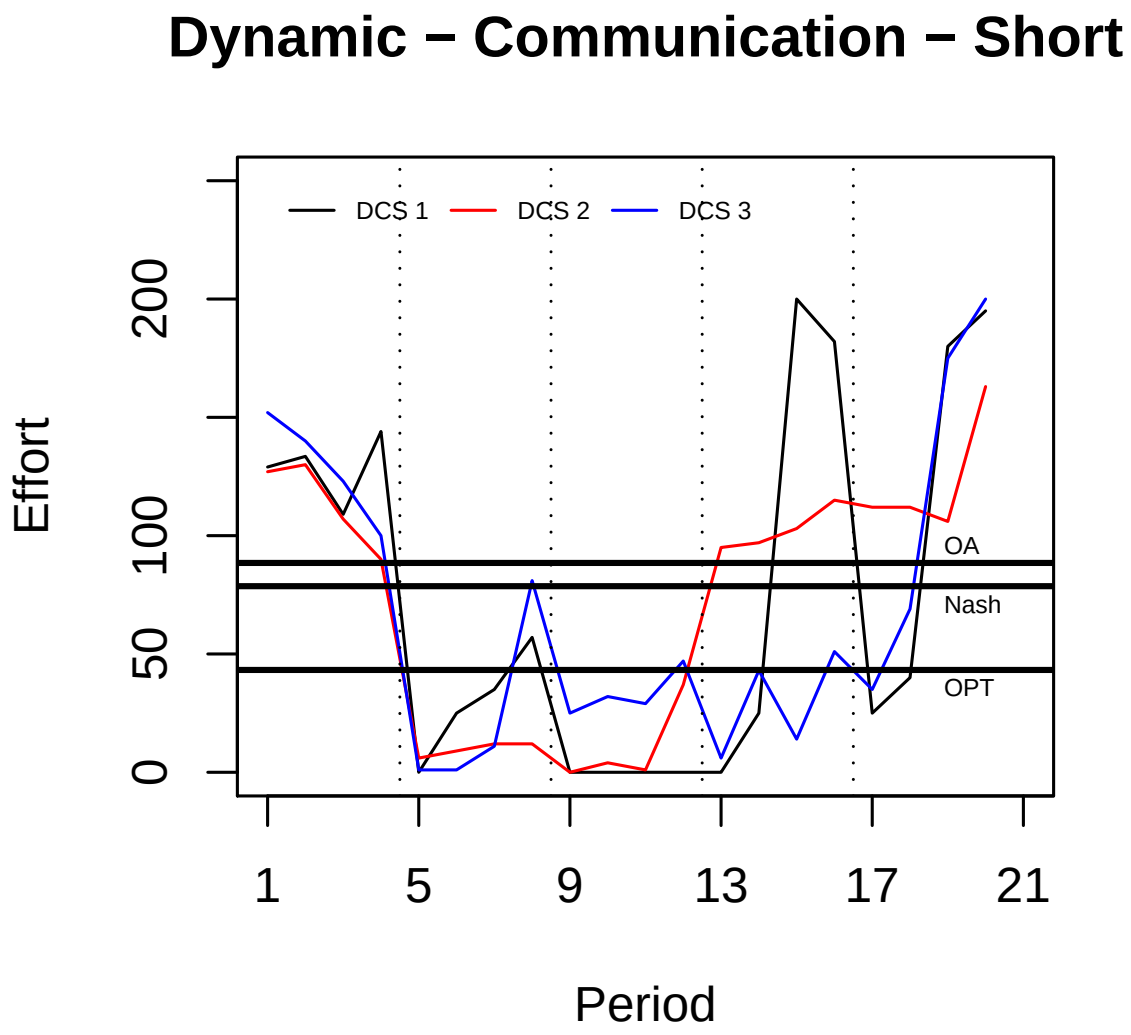
Static, Communication



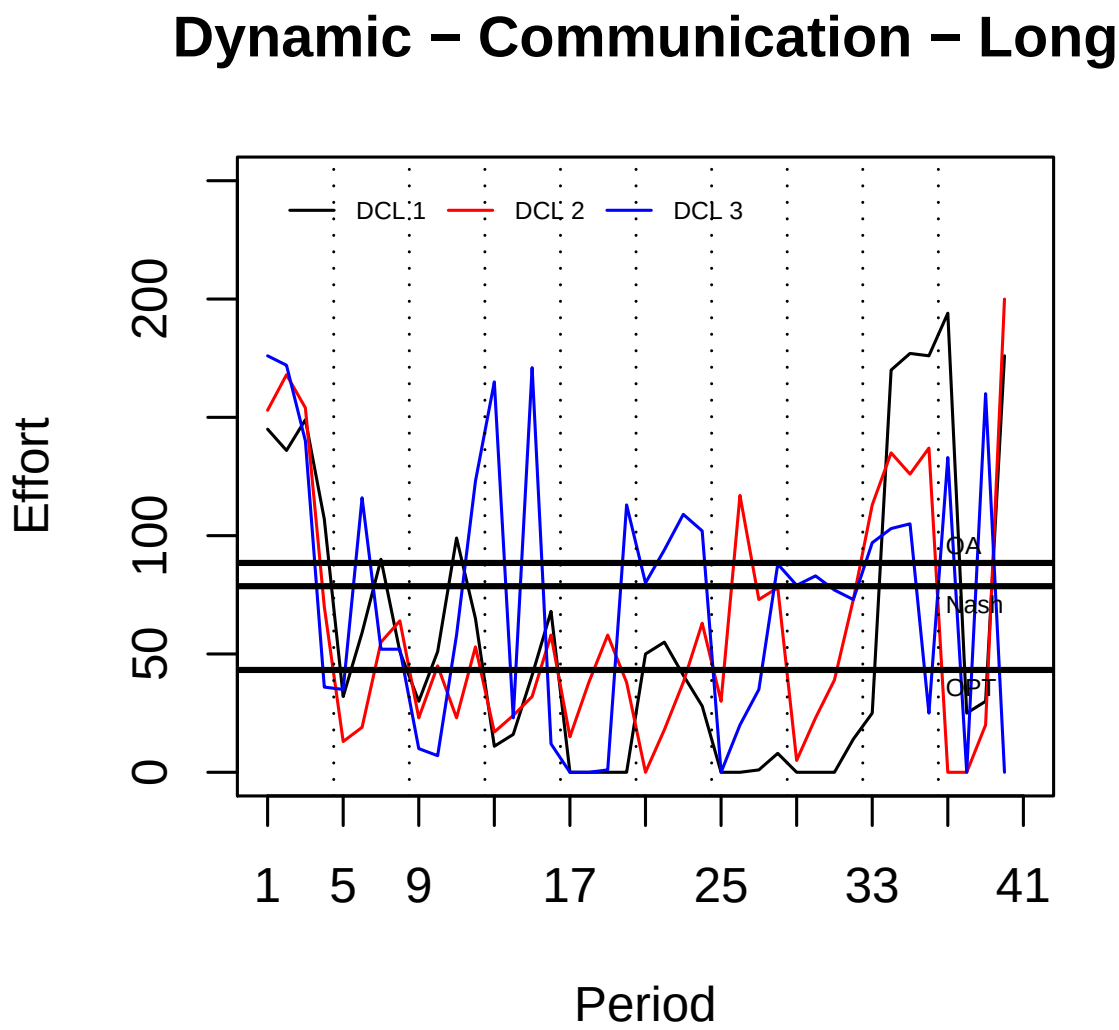
Dynamic, No Communication



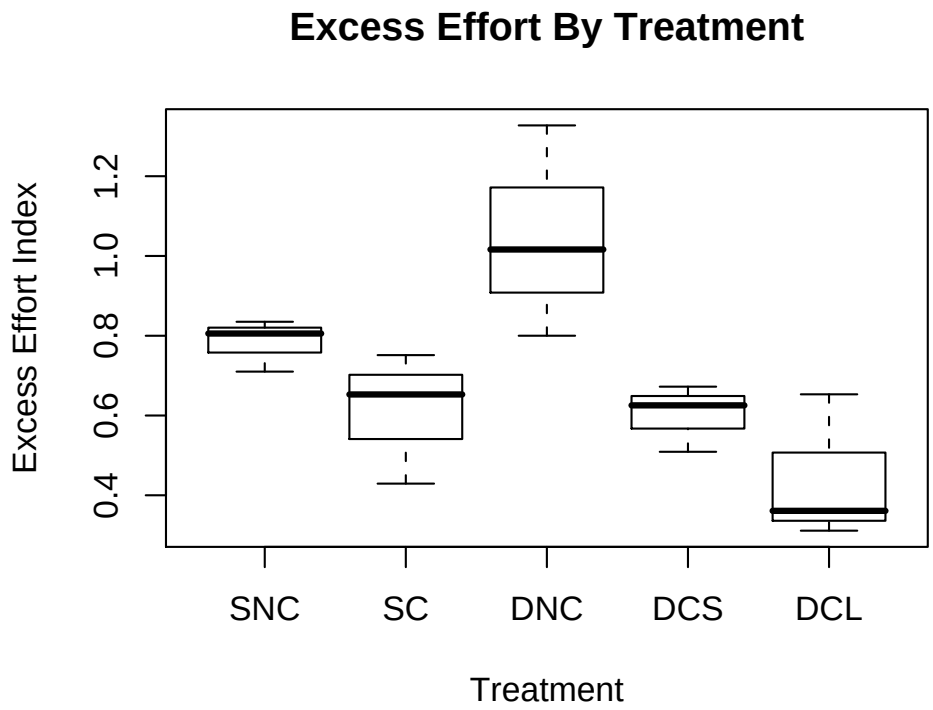
Dynamic, Communication, Short



Dynamic, Communication, Long



Excess Effort



$$\texttt{x.effort} = \frac{e_s - e_s^*}{e_s^{oa} - e_s^*}$$

Analysis of Variance in Excess Effort

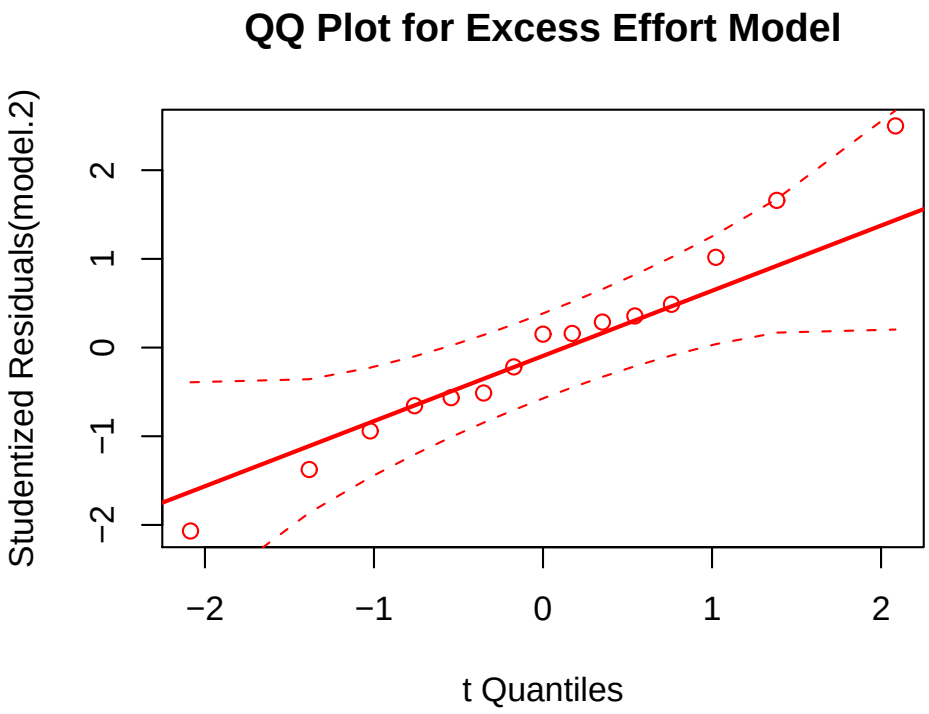
Mean Effort by Treatment

	Static	Dynamic	Mean
No Communication	0.78	1.05	0.92
Communication/Short	0.61	0.60	0.61
Communication/Long		0.44	0.44
Mean	0.70	0.70	0.70

ANOVA

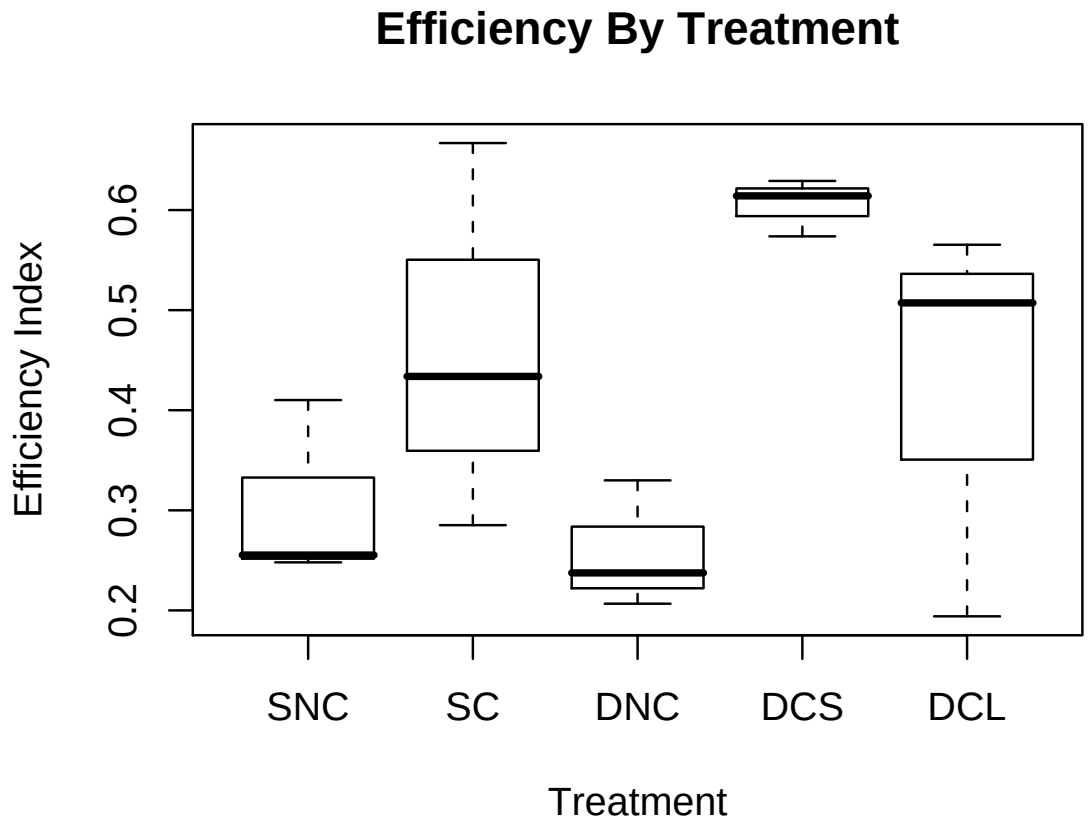
	Df	Pr(>F)
Dynamic	1	.9997
Communication	1	.0020
LongSession	1	.1069
Dynamic:Communication	1	.1921
Residuals	10	

Specification Test



Residuals lie within the simulated 95% confidence bounds.

Efficiency Data



$$\texttt{efficiency} = \frac{\pi_s - \pi_s^{oa}}{\pi_s^* - \pi_s^{oa}}$$

Analysis of Aggregate Efficiency

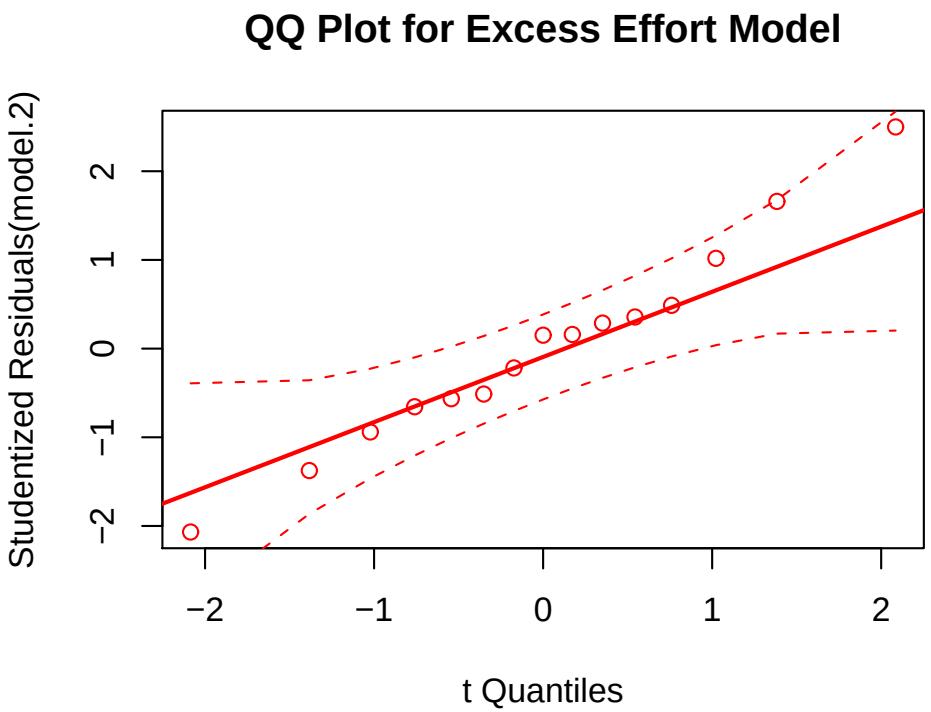
Mean Efficiency by Treatment

	Static	Dynamic	Mean
No Communication	0.30	0.26	0.28
Communication/Short	0.46	0.61	0.53
Communication/Long		0.42	0.42
Mean	0.38	0.43	0.41

ANOVA

	Df	Pr(>F)
Dynamic	1	0.5357
Communication	1	0.0139
LongSession	1	0.2148
Dynamic:Communication	1	0.2483
Residuals	10	

Specification Test (Efficiency Model)



Conclusions

- Dynamic environment is feasible to implement and easily understood.
- Within sessions variation is stronger in dynamic environments.
- Between sessions
  - significant communication effect
  - no model specification effect
  - no strong interaction effect

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Future Work

- Further replications
- Revise timing of growth increment
- Experiment with Group Solidarity Incentives

Thank you for your attention.