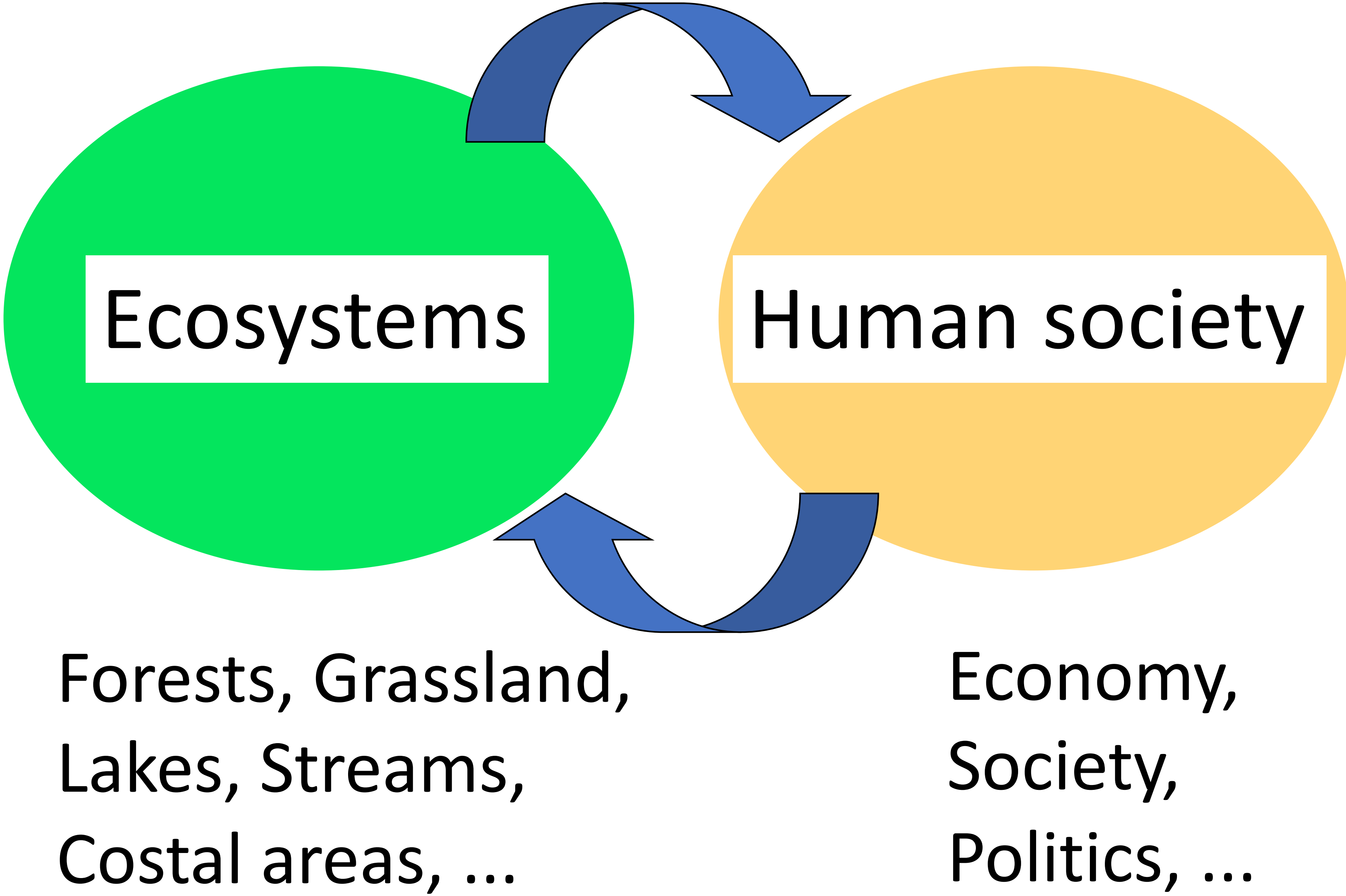
Banff International Research Station Workshop Online
Mathematics of Human Environmental Systems
Jan. 25, 2021; 13:10–13:55 (MST)

Persistence of corruption: an evolutionary game theory motivated by illegal logging in tropics

Yoh Iwasa
(Kwansei Gakuin Univ, Japan)

done in collaboration with
Joung-Hun Lee, Ulf Dieckmann, Karl Sigmund, Y. Kubo,
R. Fujiwara, R.M. Septianad, and S. Riyantold


Ecosystems
Human society
Forests, Grassland,
Lakes, Streams,
Costal areas, ...
Economy,
Society,
Politics, ...

Irregal logging

Illegally logged rainforest tree in Gunung Palung National Park in Indonesia

Cleared area in Cambodia
(http://www.chiangraitimes.com/news/16262.html)

Table 2.1. Indicative Estimates of Illegal Logging Selected Countries

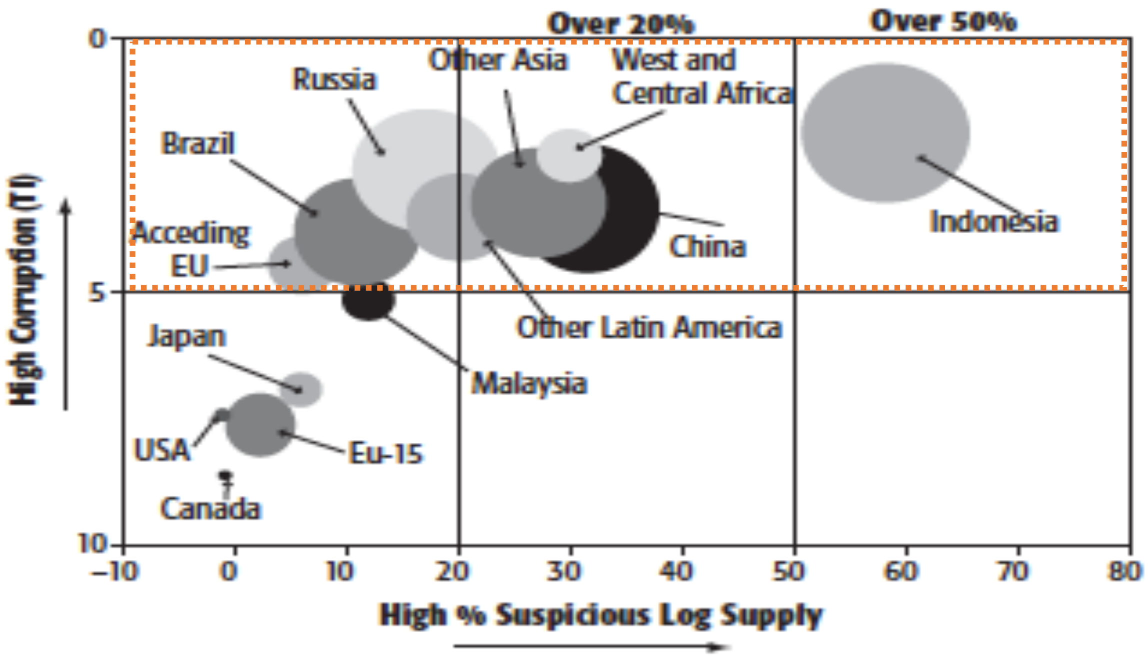
(various years)

Country	Percent of total production
Bolivia	80
Brazil	20–47
Cambodia	90
Cameroon	50
Colombia	42
Ecuador	70
Gabon	70
Ghana	60
Indonesia	70–80
Laos	45
Malaysia	Up to 35
Myanmar	50
Papua New Guinea	70
Peru	80
Russia	10–15 (northwest) 50 (far east)
Thailand	40
Vietnam	20–40

Sources: Savcor Indufor Oy (2004); Seneca Creek Associates and Wood Resources International (2004); FAO (2005); European Forest Institute (2005).

In many tropical countries,
forest is in danger
of illegal logging.

Illegal logging and Corruption are correlated



Source: Seneca Creek Associates (2004).
Note: Bubble size represents the volume of suspect round-wood, including imports.

Two theoretical models of illegal logging in tropical forests

[1] Profit sharing suppresses illegal logging

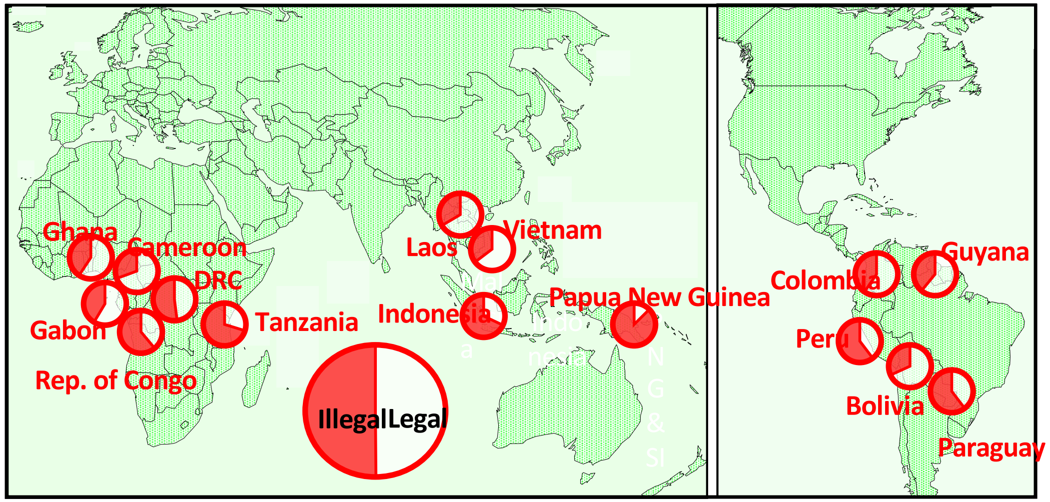
[2] Illegal logging is a result of corruption

Two theoretical models of illegal logging in tropical forests

[1] Profit sharing suppresses illegal logging

[2] Illegal logging is a result of corruption

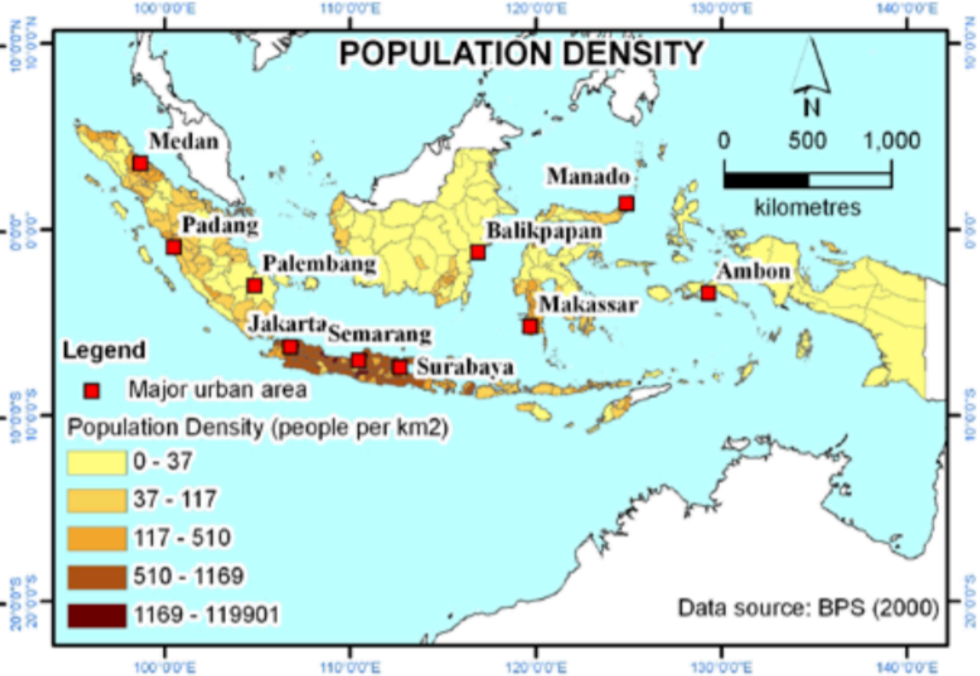
Profit-sharing and agroforestry in Indonesian tropical forests with high risk of illegal logging



www.redd-monitor.org

Lee,, J-H., Y. Kubo, R. Fujiwara, R.M. Septianad, S. Riyantol, & Y. Iwasa 2018. Profit sharing as a management strategy for a state-owned teak plantation at high risk for illegal logging. Ecological Economics 149. 140-148.

Anthropogenic pressure in Java



Center for international forestry research

caused changes in the forest use since 1997

Deforestation in Java by illegal logging

Teak Forest
(www.mm.feb.ugm.ac.id)

Signs of illegal logging
(www.mm.feb.ugm.ac.id)

Locals involve in surveillance to suppress illegal logging

Table 5. Transition of illegal logging after the introduction of PHBM in KPH Pemalang

Year	Number of illegal logging incidents	Damage (1,000 Indonesian Rupiah)
2004	601	1,618,363
2005	478	1,100,585
2006	422	617,269
2007	190	418,484
2008	143	107,834
2009	107	85,780
2010	74	96,176
Total	2,015	4,044,491

Decreased Incidents

Source: Statistics of Perhutani, KPH Pemalang

10 yen is about 1,000 Rupiah

Fujiwara et al., 2012

Profit sharing from timber harvest

Few forests apply profit-sharing management

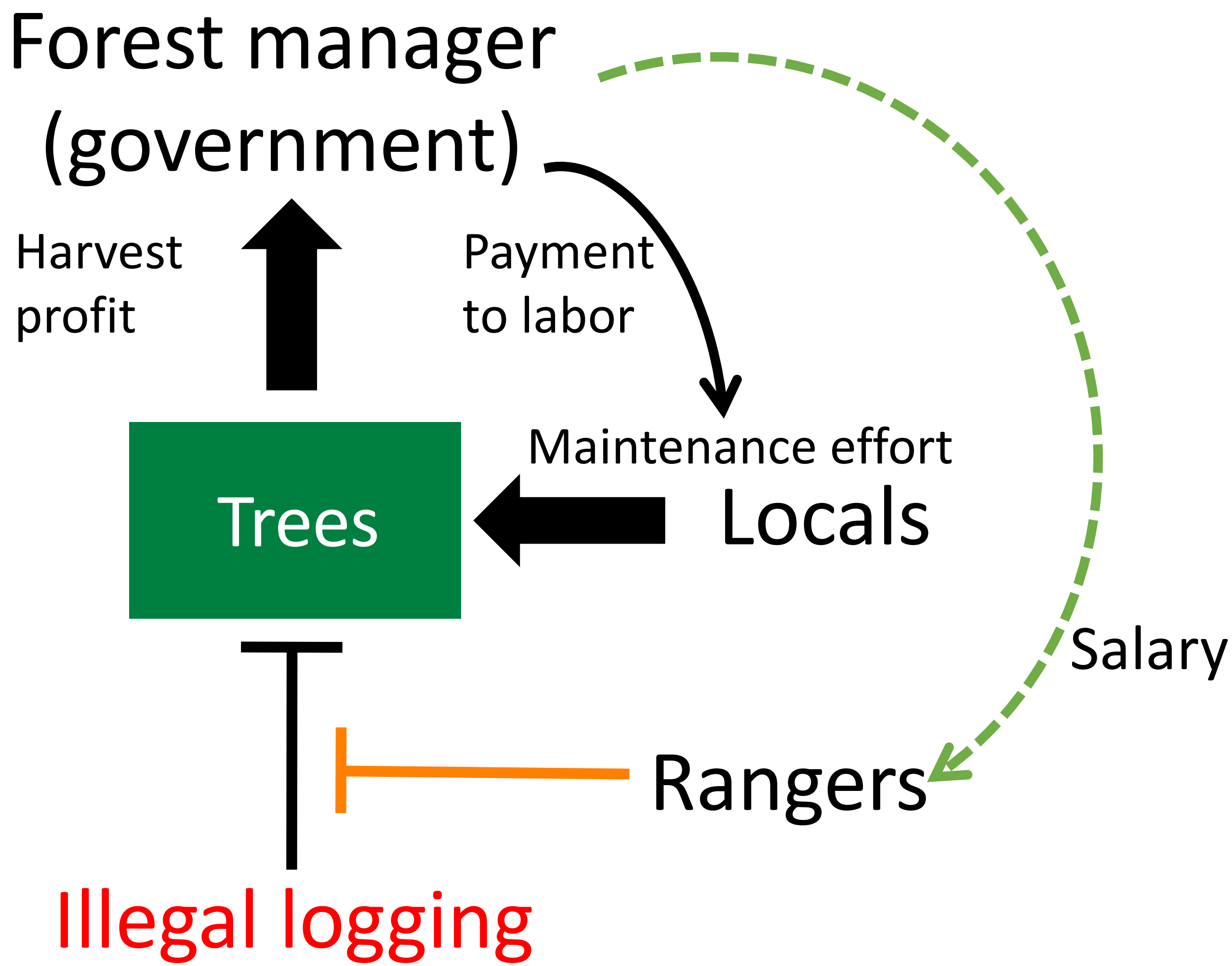
Table 1. Contract configuration of PHBM

Type of contract		Sharing rate (%) (Tender)		
		Perhutani	Investor	LMDH
General	Bilateral	75 (Land and Funds)	— (—)	25 (Labour)
Special	Bilateral	40 (Land)	— (—)	60 (Funds and Labour)
	Trilateral	40 (Land)	30 (Fund)	30 (Labour)

Source: Contract document of PHBM at Glandang and Surajaya villages, Field research (2010; 2011)

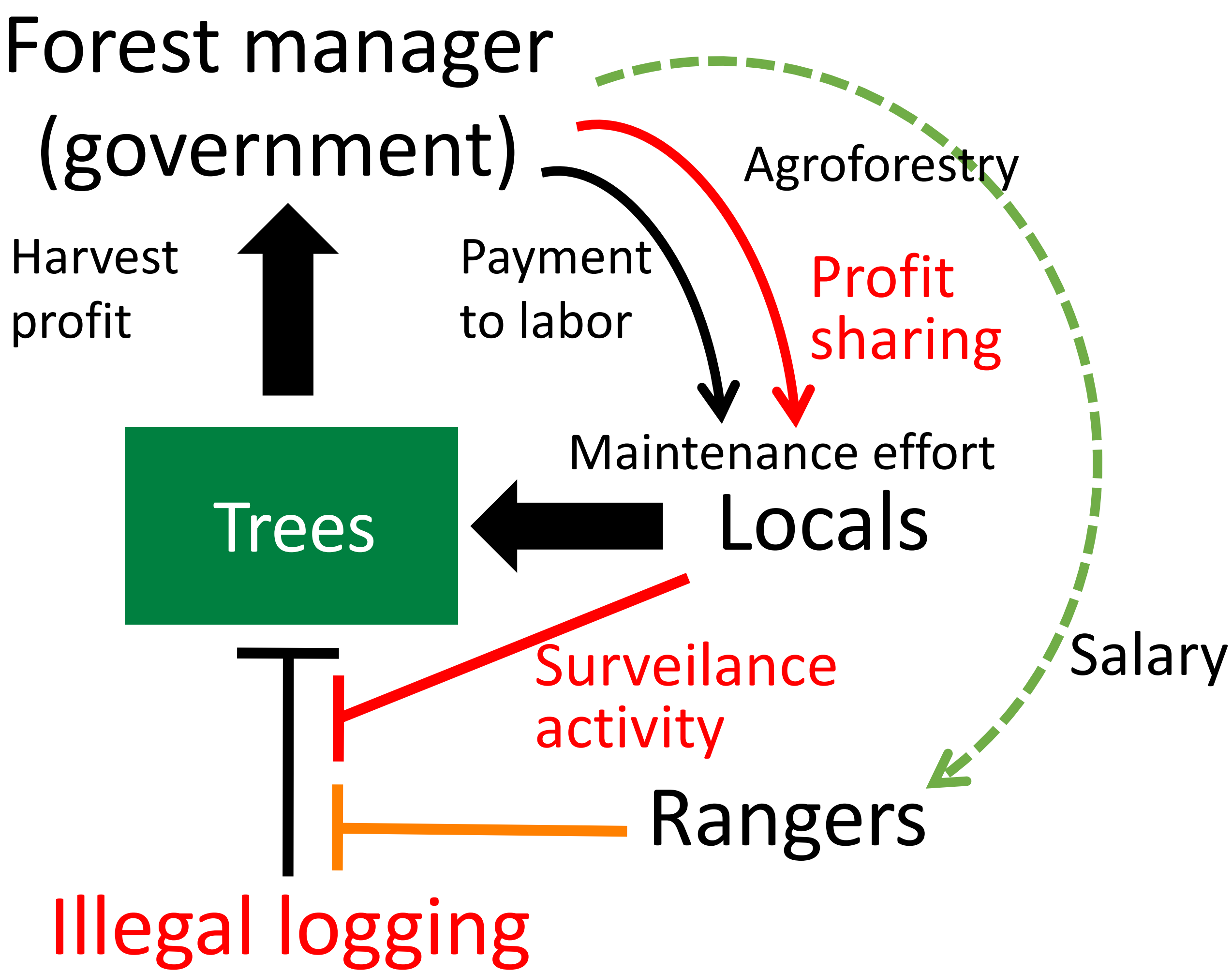
Fujiwara et al., 2012

Management plan



Rangers cannot stop illegal logging

Management plan



Profit sharing makes local people help in suppressing illegal logging by surveillance

Value to the manager expected future profit (site of trees age *t*)

$$V_t = \max_{0 \le \sigma_t \le 1} \begin{cases} \sigma_t \left[(1-\alpha) p_0 t^3 - c + e^{-r} V_0 \right] \\ + (1-\sigma_t) \left[\left(1 - s(1-L_t)\right)\left(-c + e^{-r} V_0\right) + s(1-L_t) e^{-r} V_{t+1} \right] \end{cases}$$

Cut trees

harvest profit, payment to worker, site value age 0

Wait

natural disturbance/ illegal logging

survival from the disturbance

σ_t owner's choice of cutting trees

L_t disturbance by stealing

α rate of profit sharing

c payment to workers

Value to workers
expected future profit (site of trees age *t*)

Decision of manager

$$U_t = \sigma_t \left[\alpha p_0 t^3 + c + agro + e^{-r} V_0 \right]$$

$$+ (1-\sigma_t) \max_{0 \le M_t \le N_w} \left\{ \left[\left(1 - s(1-L_t)\right)\left(c + agro + e^{-r} U_0\right) + s(1-L_t) e^{-r} U_{t+1} \right] \right\}$$

disturbance survival

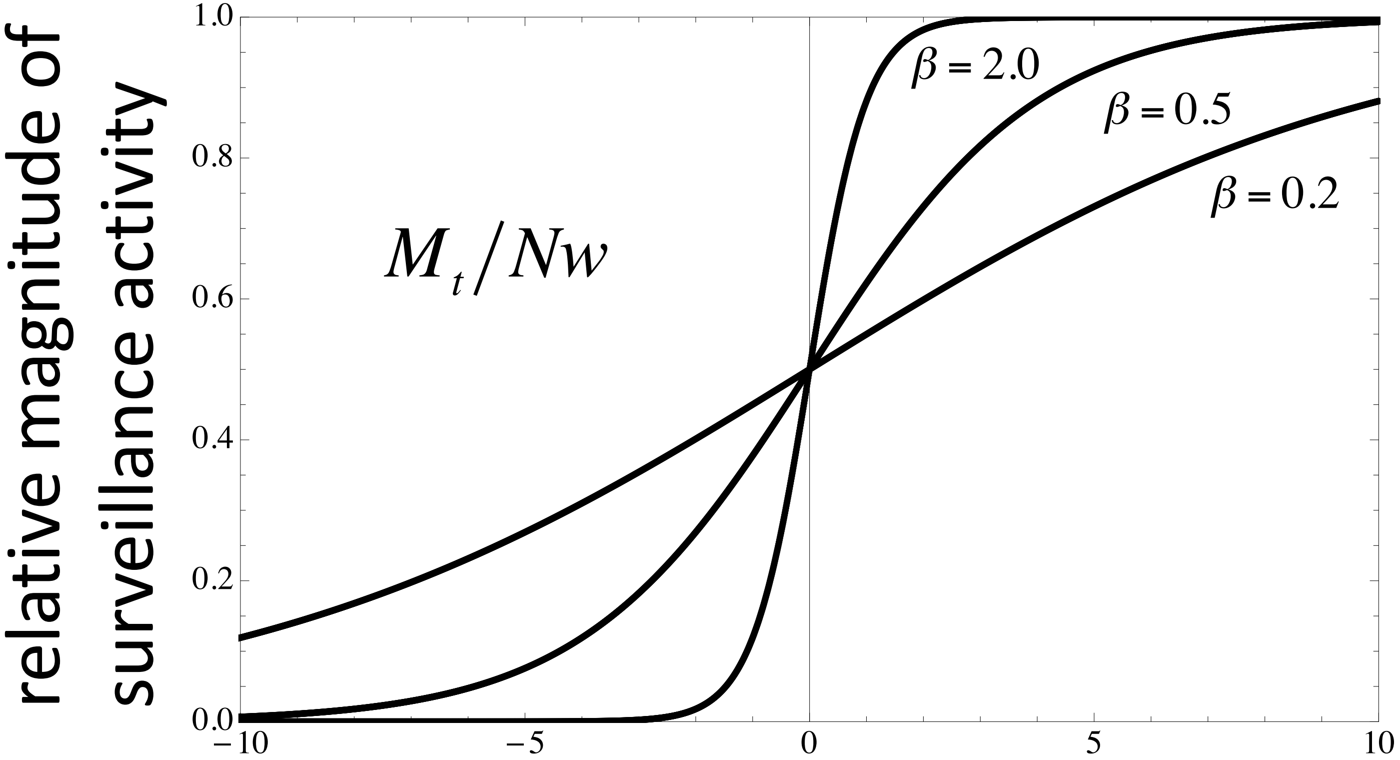
$$L_t = \frac{N_{IL}}{N_{IL} + e(h + M_t)}$$

M_t: Participate to surveillance activity

c Payment of labor from manager

$agro$ Income from crop production

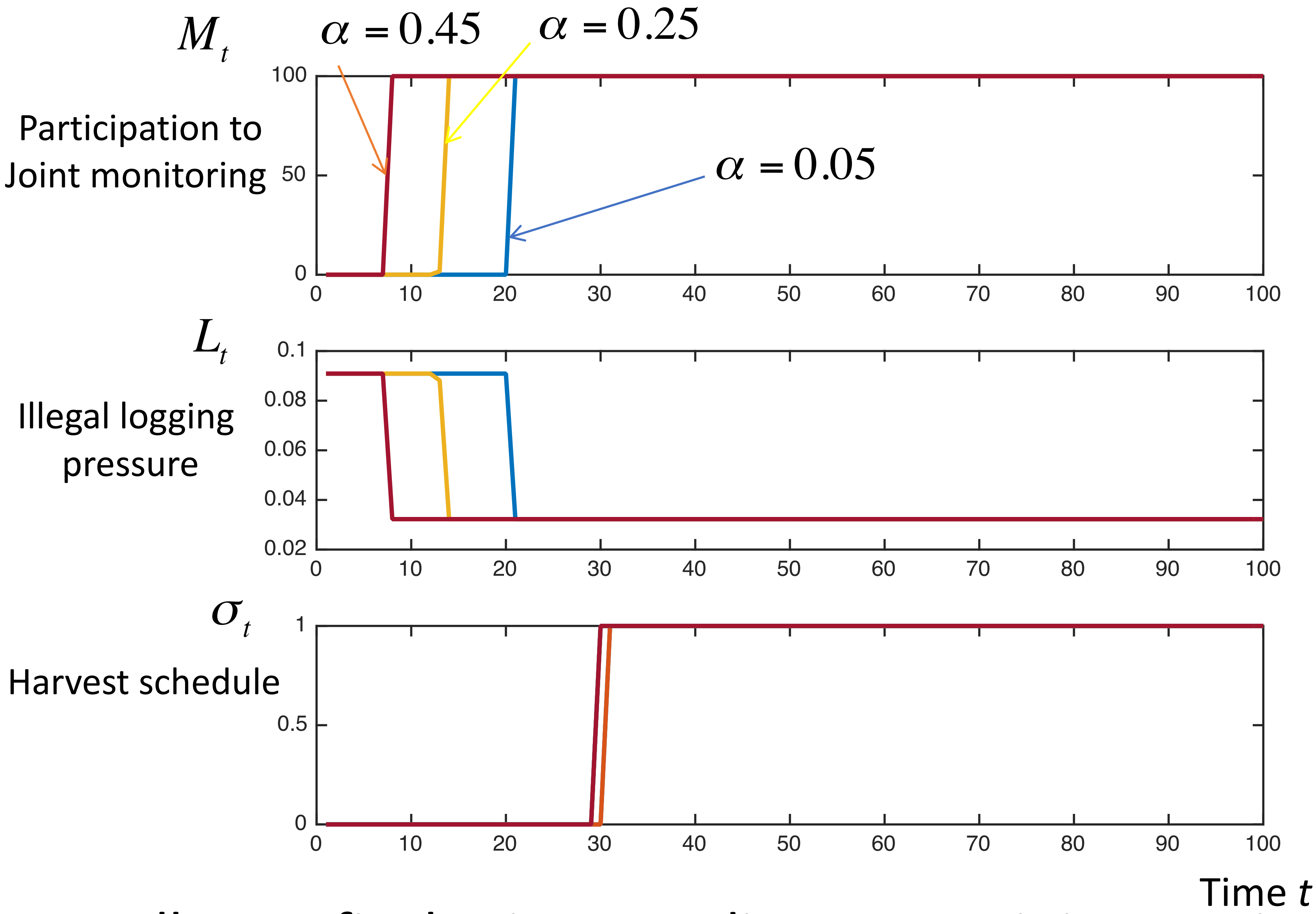
Surveillance acitivity follows logit dynamics (stochastic best response)



Differential utility $U_{protected} - U_{cleared}$

$$U_{cleared} = c + agro + e^{-r}U_0 \qquad U_{protected} = e^{-r}U_{t+1}$$

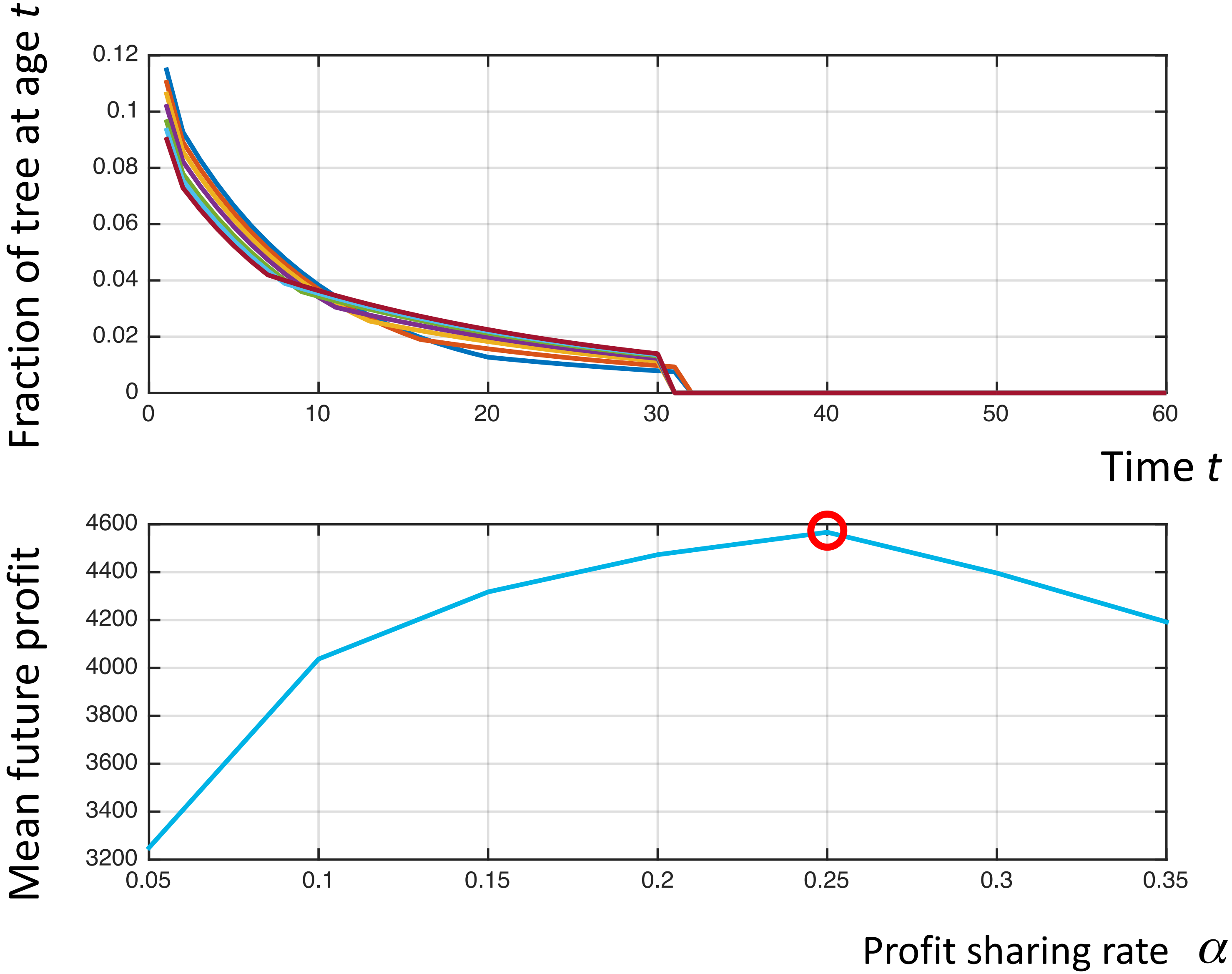
Corresponding decisions on harvesting time



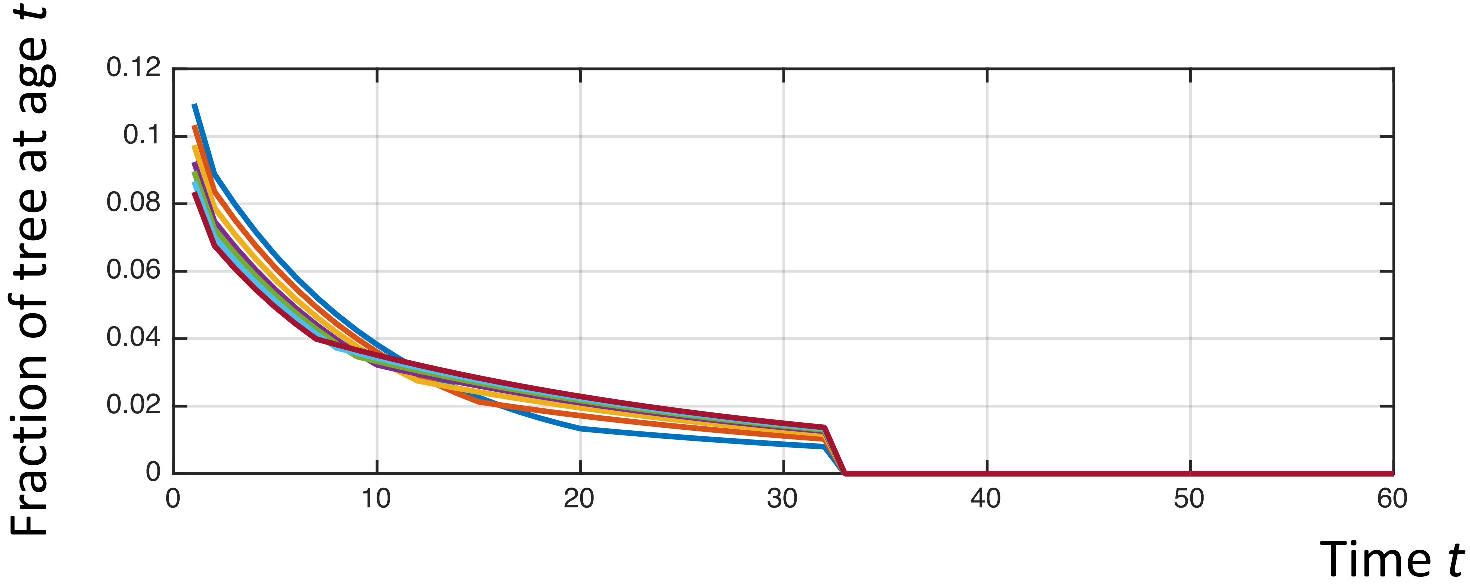
Smaller profit sharing rate discourages joint monitoring

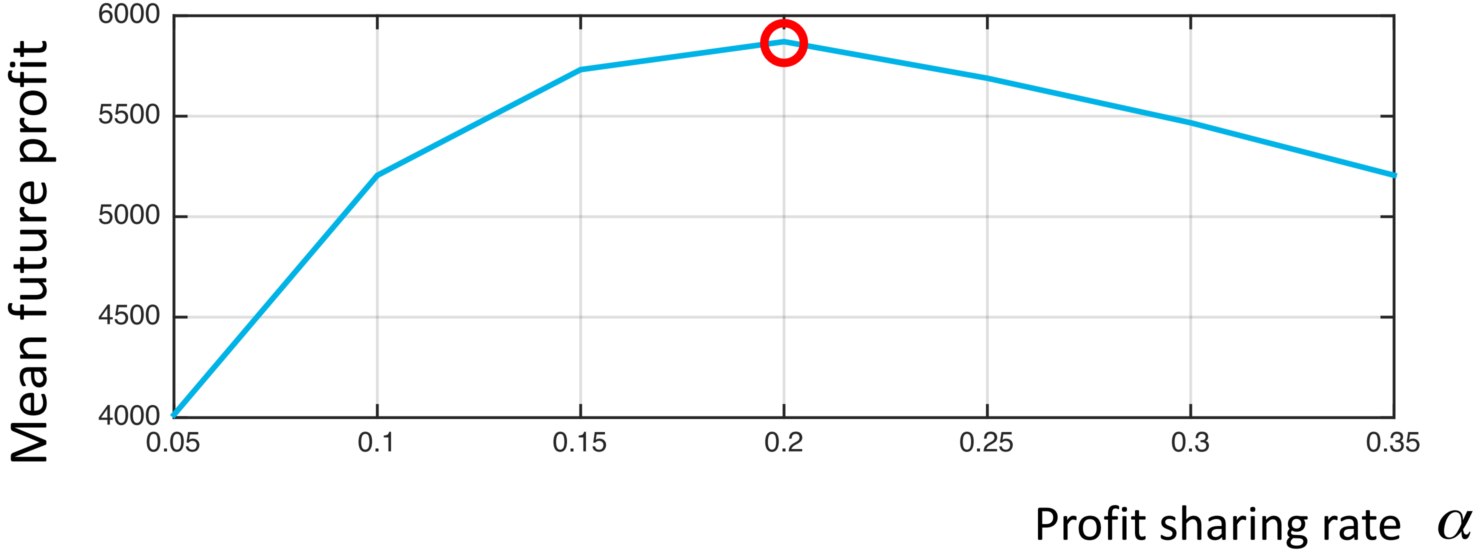
Optimal profit-sharing rate α

Finding optimal profit sharing rate



Natural disturbance gets lower (*s* is higher)





Low natural disturbance (large s),

Low sensitivity to utility difference (small β),

Small discounting rate (small r),

Low maintenance cost (small c)

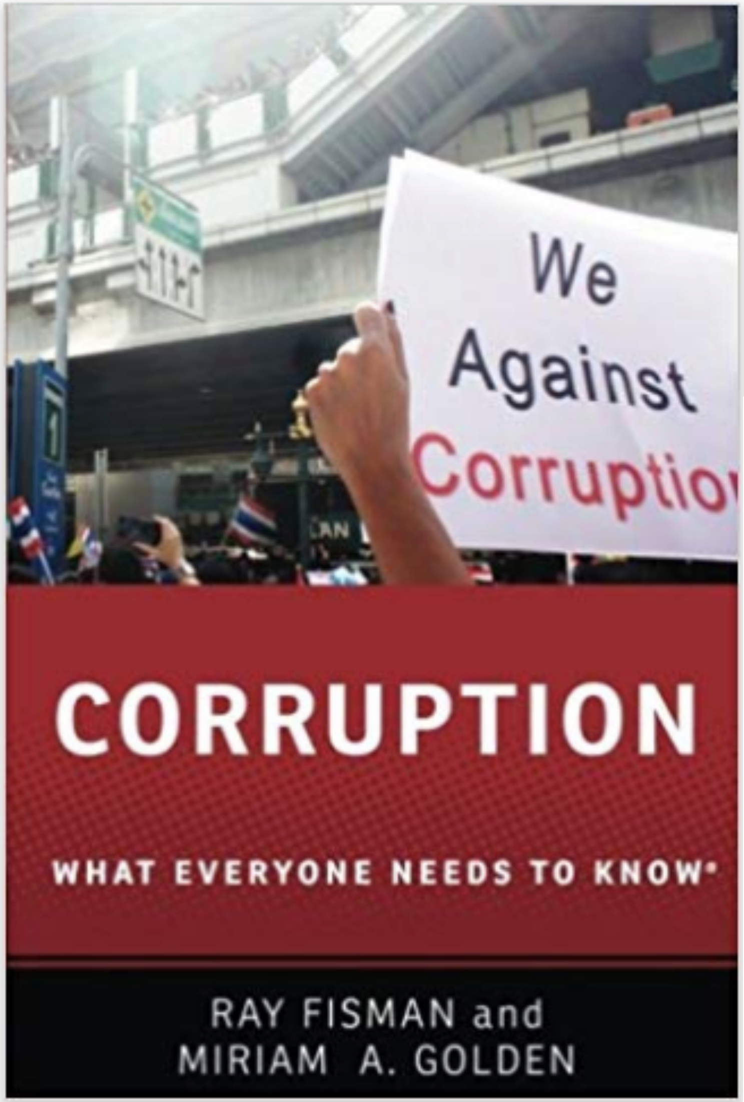
Smaller profit-sharing fraction α.

The decision on resource management
should vary with
ecological and social parameters.

Two theoretical models of illegal logging in tropical forests

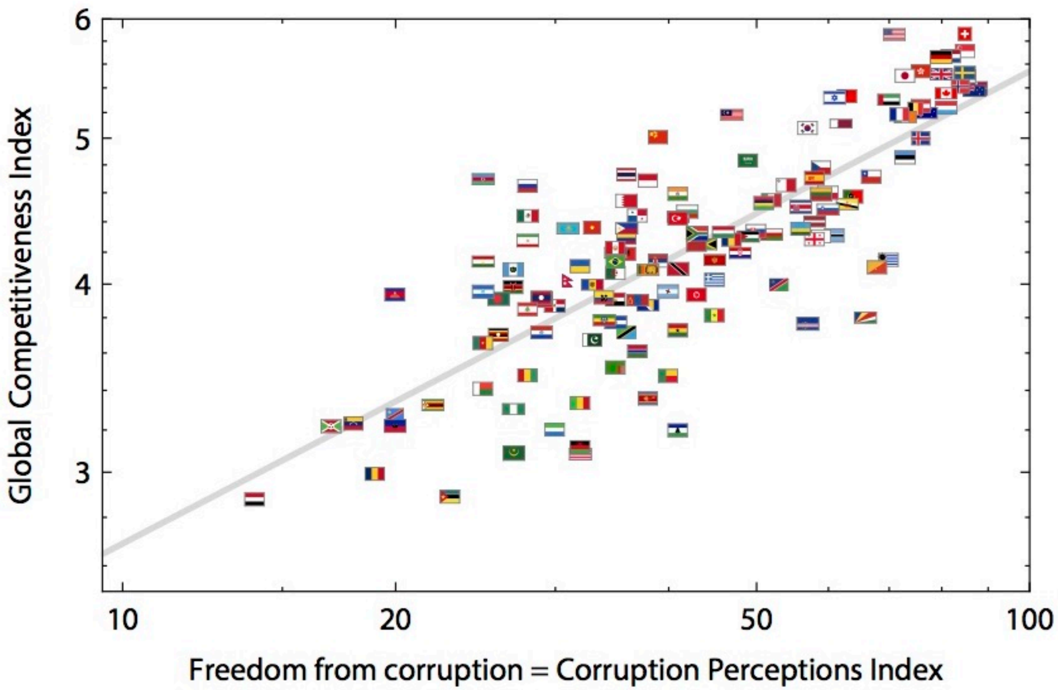
[1] Profit sharing suppresses illegal logging

[2] Illegal logging is a result of corruption



R Fisman and MA Golden (2017)
“Corruption: What everyone needs to know.”
Oxford Univ. Press

Freedom from corruption is strongly correlated with economic success



Social evolution leads to persistent corruption

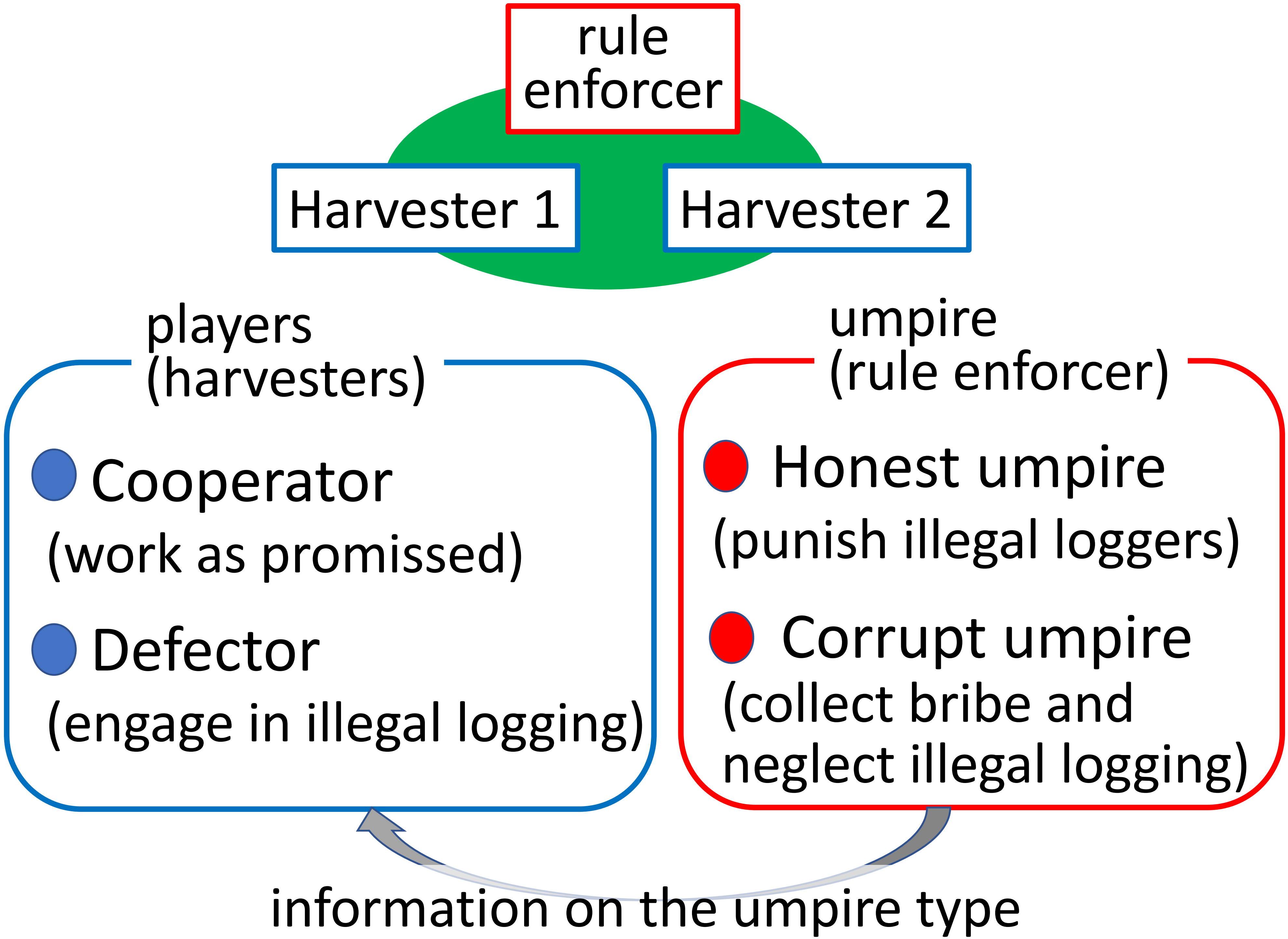
Joung-Hun Lee[a,b], Yoh Iwasa[b,c], Ulf Dieckmann[d,e], and Karl Sigmund[d,f,1]

[a]Institute of Decision Science for a Sustainable Society, Kyushu University, 819-0395 Fukuoka, Japan; [b]Department of Biology, Kyushu Unive
819-0395 Fukuoka, Japan; [c]Department of Bioscience, School of Science and Technology, Kwansei-Gakuin University, 669-1337 Sanda-Shi H
[d]Evolution and Ecology Program, International Institute for Applied Systems Analysis, 2361 Laxenburg, Austria; [e]Department of Evolutiona
Biosystems, The Graduate University for Advanced Studies (Sokendai), Hayama, Kanagawa 240-0193, Japan; and [f]Faculty for Mathematics,
Vienna, 1090 Vienna, Austria

Edited by Brian Skyrms, University of California, Irvine, CA, and approved May 16, 2019 (received for review January 3, 2019)

Cooperation can be sustained by institutions that punish free-riders. Such institutions, however, tend to be subverted by corruption if they are not closely watched. Monitoring can uphold the enforcement of binding agreements ensuring cooperation, but this usually comes at a price. The temptation to skip monitoring and take the institution's integrity for granted leads to outbreaks of corruption and the breakdown of cooperation. We model the corresponding mechanism by means of evolutionary game theory, using analytical methods and numerical simulations, and find that it leads to sustained or damped oscillations. The results confirm the view that corruption is endemic and transparency a major factor in reducing it.

power based on social trust and required by their r
or otherwise chastise rule-breakers or law-offende
Here, we analyze a basic model of this type of
means of evolutionary game theory (21–24). We
minimal model capturing key dynamics relevant f
cific systems. In particular, we show that the ada
dividual agents to the current social situation lead
or damped oscillations that reflect the waxing a
institutional corruption in response to the waning
cooperation within the society.
If institutions are viewed as "guardians" of th
then it is up to the community to "guard the guar



rule enforcer
Harvester 1
Harvester 2
players (harvesters)
Cooperator
(work as promissed)
Defector
(engage in illegal logging)
umpire (rule enforcer)
Honest umpire
(punish illegal loggers)
Corrupt umpire
(collect bribe and neglect illegal logging)
information on the umpire type

If there is no umpire $b > c$

		opponent	
		C	D
ego	C	$b-c$	$-c$
	D	b	0

If there are honest umpires

fine

$b > A > c$

		opponent	
		C	D
ego	C	$b - c - f$	$-c - f$
	D	$b - A - f$	$-A - f$

$b - c > f$

If there are corrupt umpires

bribe

$b > c > B$

		opponent	
		C	D
ego	C	$b - c - f$	$-c - f$
	D	$b - B - f$	$-B - f$

“Prudent Cooperator”

PC drops out of the game,

if the umpire is corrupt.

PC plays the game,

only if the umpire is honest.

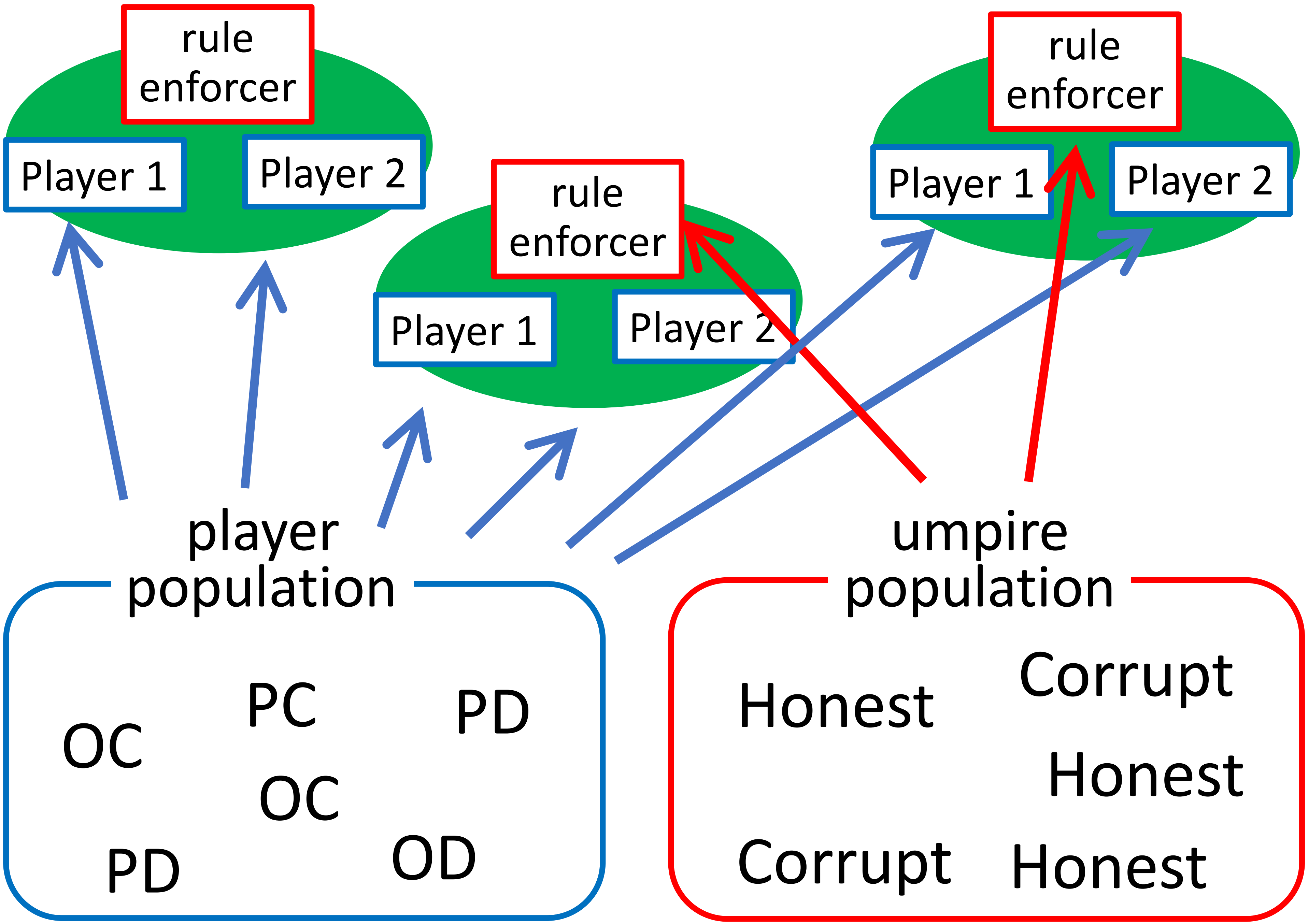
PC must pay the cost *h*
to know the umpire type

Four types of players (harvesters)

h the cost to know the umpire type

	do not pay the cost	pay the cost
	optimistic	prudent
cooperator	OC	PC
defector	OD	PD

Two-population replicator dynamics


rule enforcer
Player 1
Player 2
rule enforcer
Player 1
Player 2
rule enforcer
Player 1
Player 2
player population
OC
PC
PD
OC
PD
OD
umpire population
Honest
Corrupt
Honest
Corrupt
Honest

players (4 types): Cooperate or Defect
(harvesters) Optimistic or Prudent

Payoffs. If the umpires are all honest, the payoff matrix for OCs, PCs, ODs, and PDs is

$$Q_{\mathrm{H}} = \begin{pmatrix} b-c-f & b-c-f & -c-f & 0 \\ b-c-f-h & b-c-f-h & -c-f-h & -h \\ b-f-A & b-f-A & -f-A & 0 \\ -h & -h & -h & -h \end{pmatrix}.$$

If the umpires are all corrupt, the corresponding payoff matrix for the four types of players is

$$Q_{\mathrm{C}} = \begin{pmatrix} b-c-f & 0 & -c-f & -c-f \\ -h & -h & -h & -h \\ b-f-B & 0 & -f-B & -f-B \\ b-f-B-h & -h & -f-B-h & -f-B-h \end{pmatrix}.$$

umpire (2 types):   Honest or Corrupt

honest umpire receives

$2f$ when neither player is PD

0 when one of the players is PD

corrupt umpire receives

$2f+B$*[No. of OD or PD players]
when neither player is PC

0 when one of the players is PC

Evolutionary game simulation.

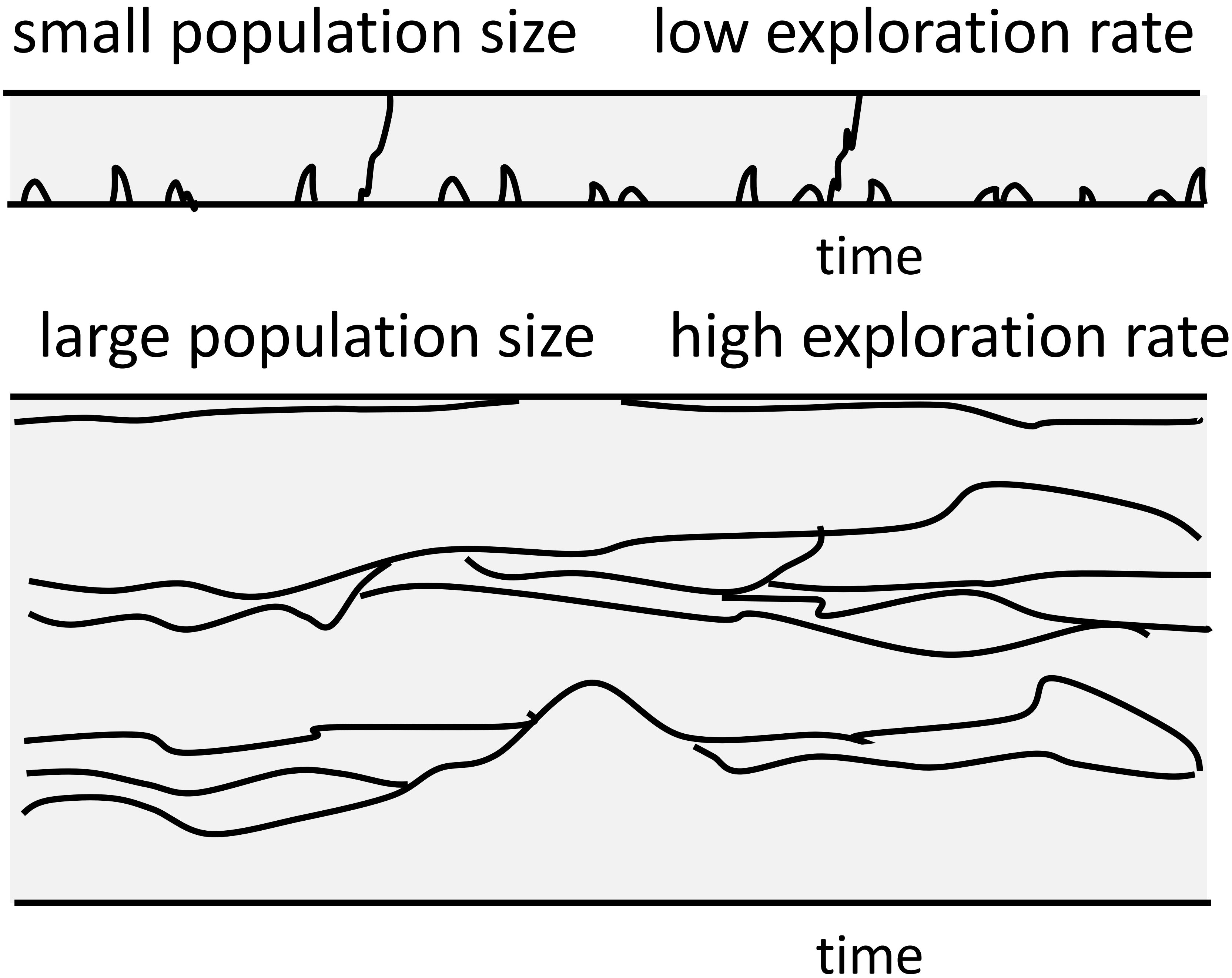
Player changes its behavior occasionally.

imitation

It tends to adopt the behavior of successful players in the population.

exploration

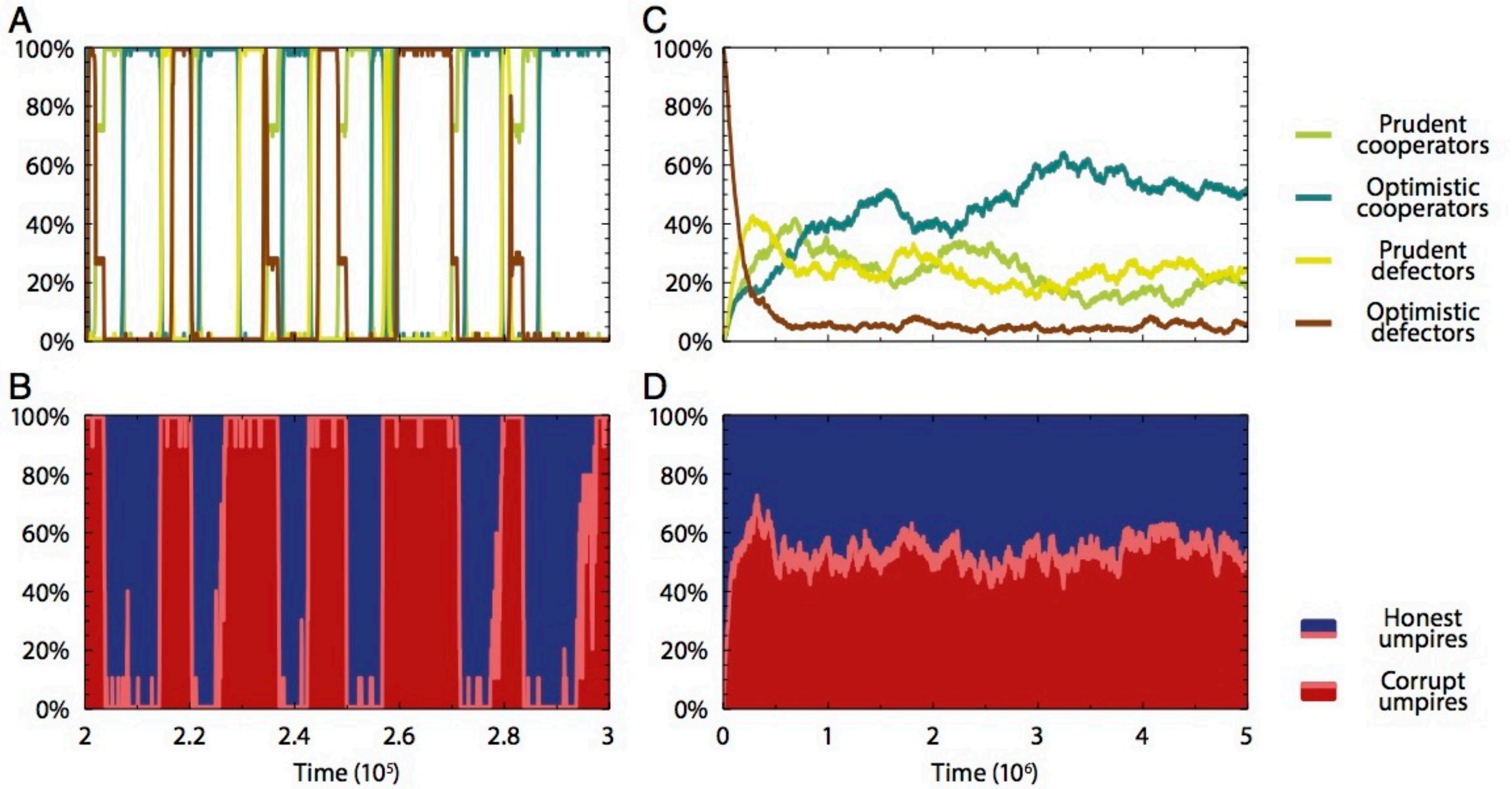
At a small rate,
a player adopts a novel behavior.


small population size
low exploration rate
time
large population size
high exploration rate
time

small population size / large population size
small exploration rate / high exploration rate

small population size
small exploration rate

large population size
high exploration rate



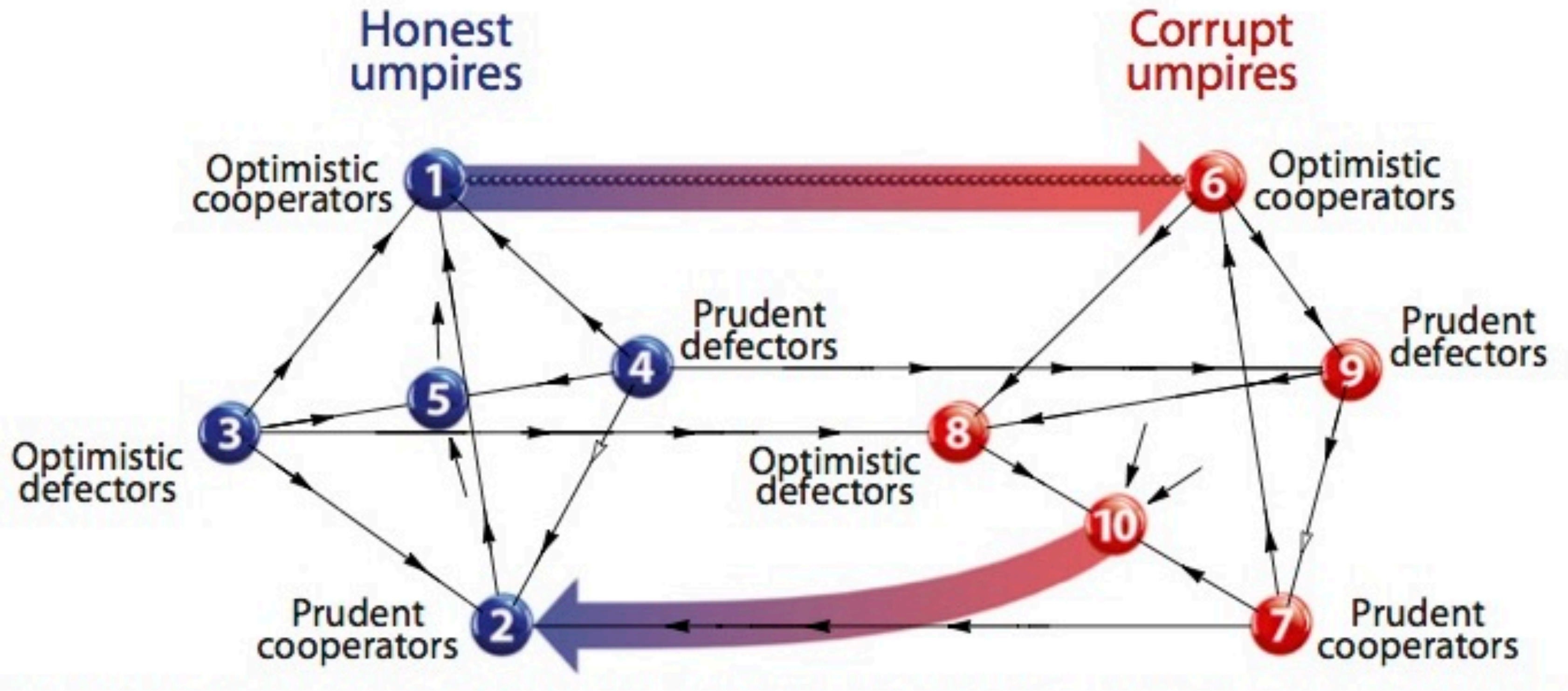
Two limits

In a small population with low exploration rate, the population is close to monomorphic.
The evolution proceeds as jumps between vertexes.

In a large population with high exploration rate, the population is a mixture of many types.
The evolution takes place as the dynamical change of their fractions.

In a small population with low exploration rate, the evolution proceeds as jumps between vertexes.

Shift from Honest to Corrupt, when OC is abundant



Shift from Corrupt to Honest, when PC is abundant

Two limits

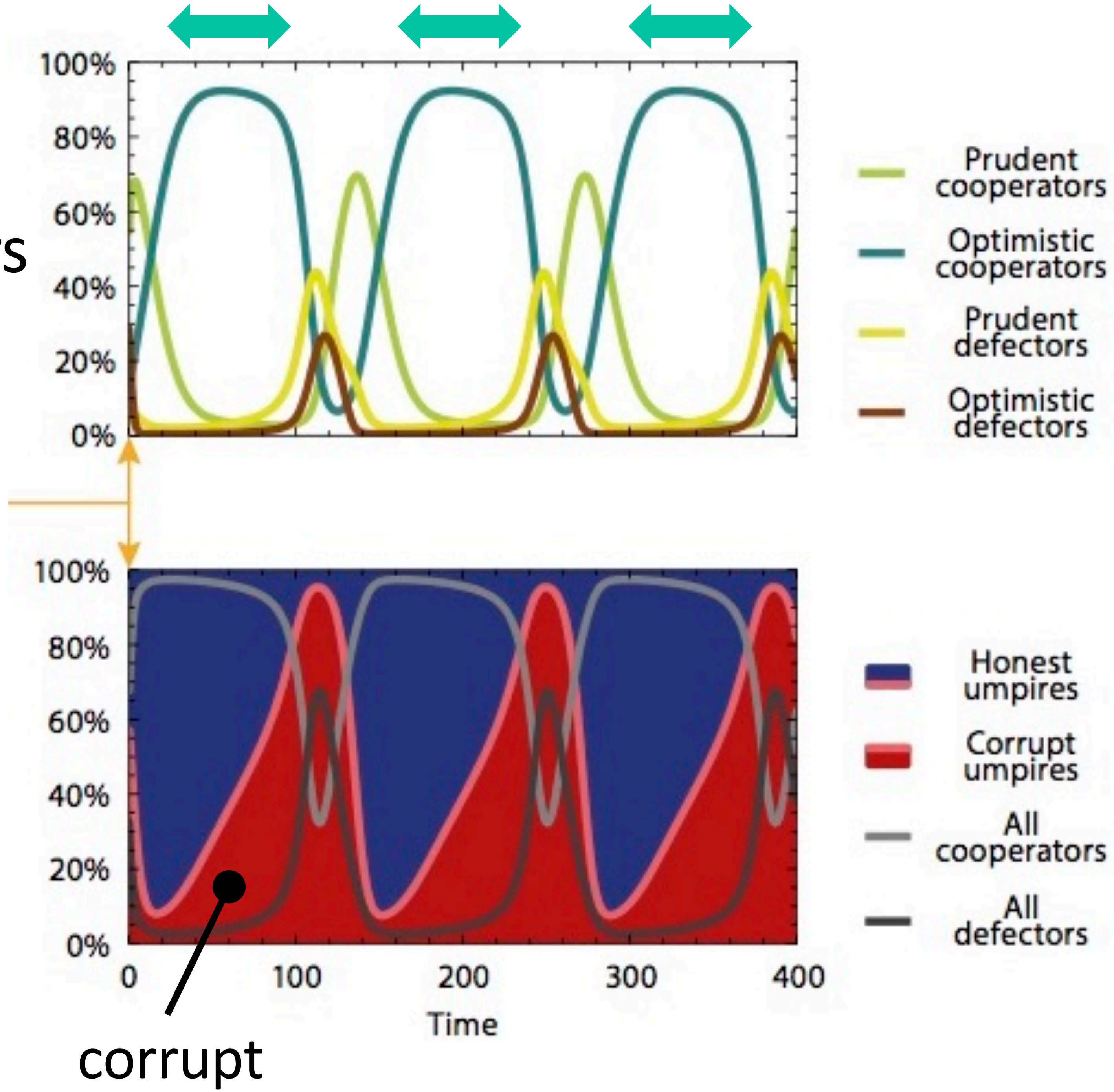
In a small population with low exploration rate, the population is close to monomorphic.
The evolution proceeds as jumps between vertexes.

In a large population with high exploration rate, the population is a mixture of many types.
The evolution takes place as the dynamical change of their fractions.

OC dominates

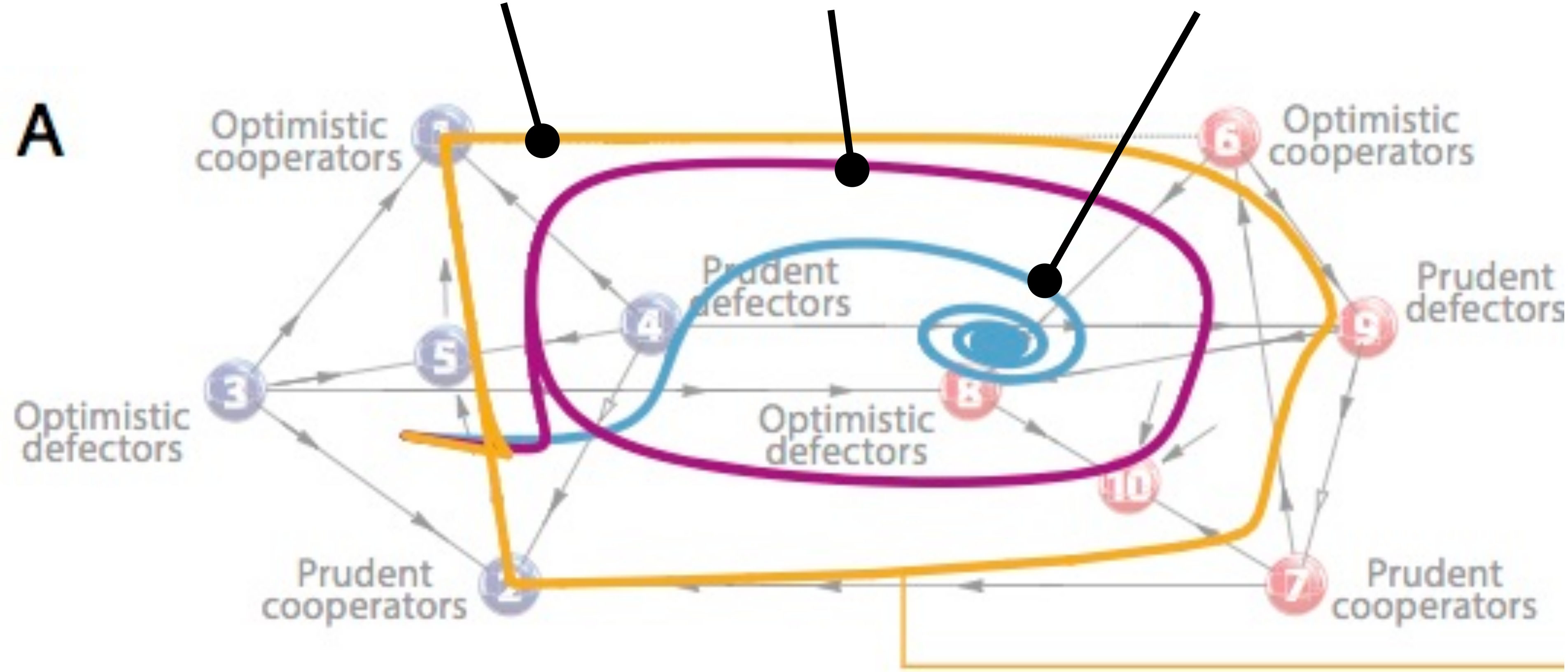
optimistic cooperators dominate

corrupt umpires increase



exploration rate is

small intermediate large

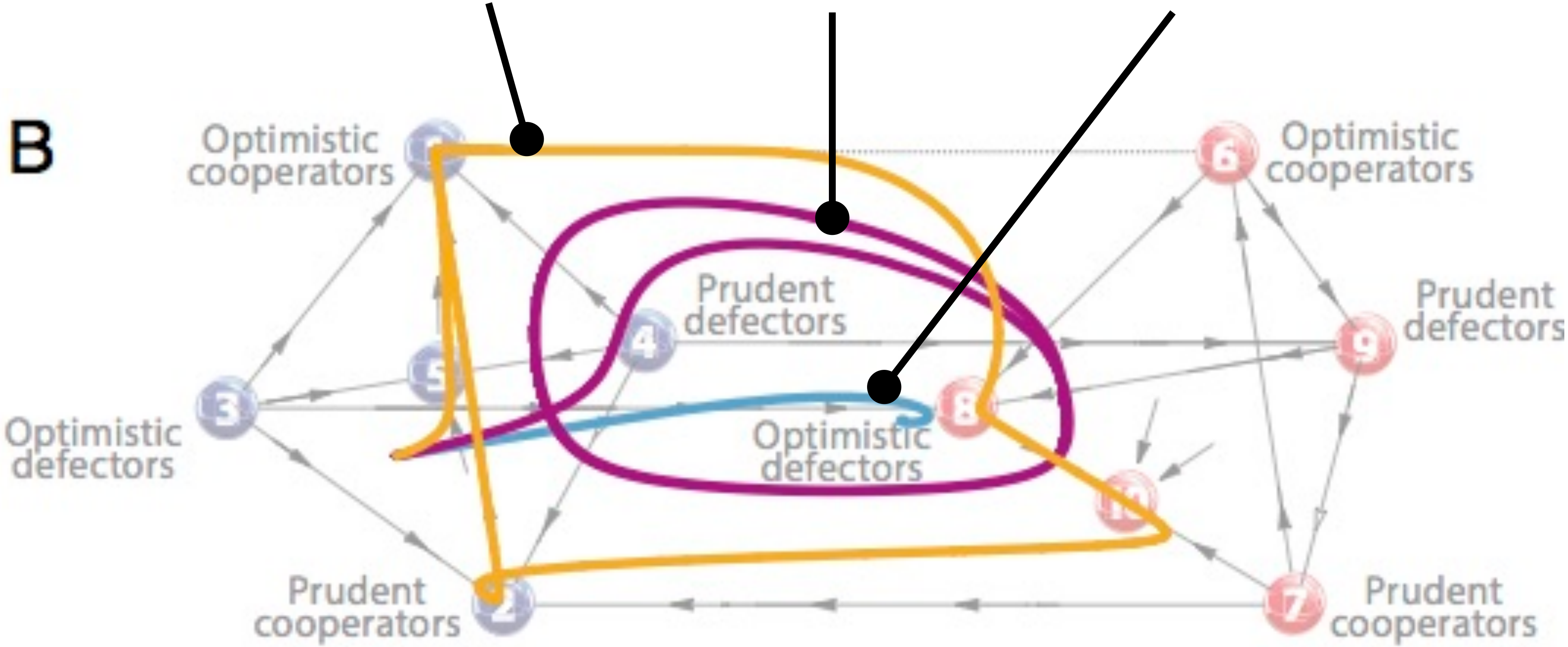


population size is large; replicator dynamics

Penalty *A* is large

exploration rate is

small intermediate large



population size is large; replicator dynamics

Penalty *A* is small

Conclusion

Corruption would not disappear.

[1] It always exists a considerable fraction,

or

[2] it occasionally comes back.

Thank you for listening!