Distributional Effects of Catch-Quota Management Regimes in a Heterogeneous and Uncertain Environment

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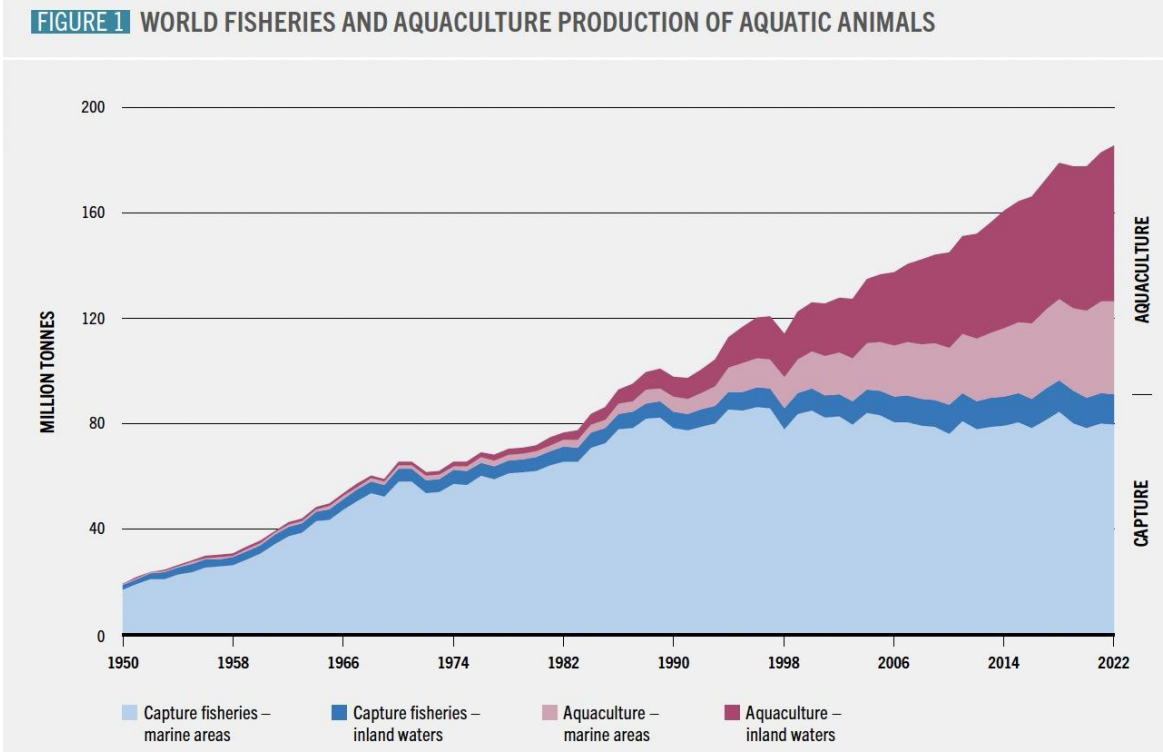
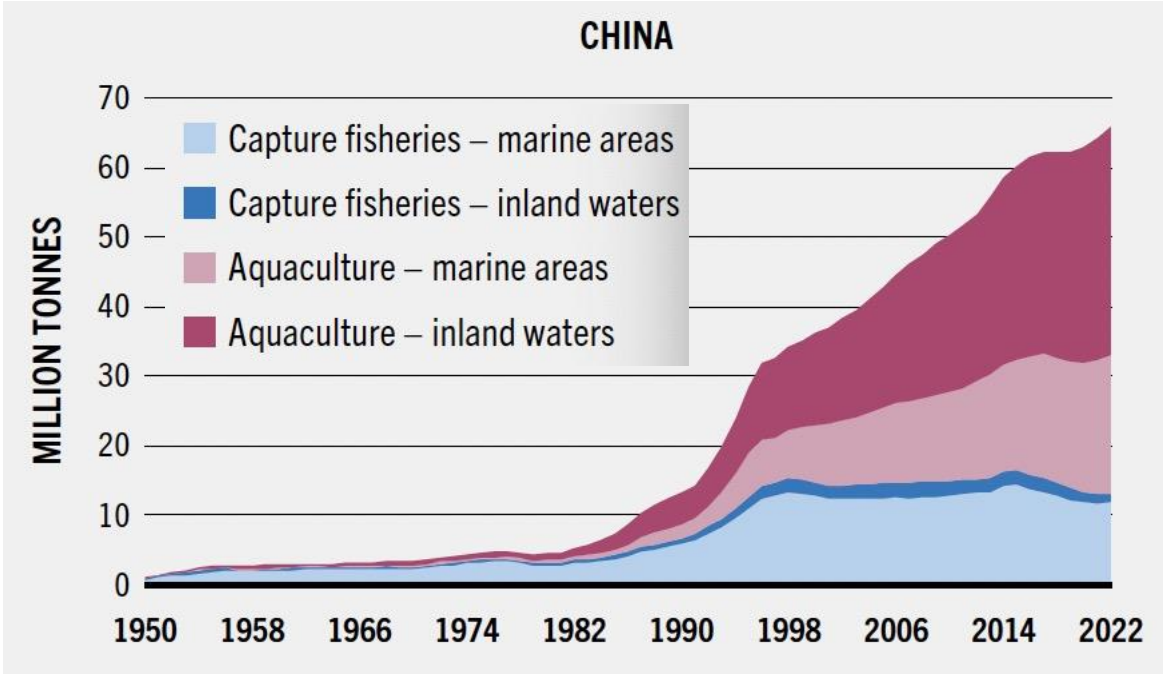
Background

- FAO (2024)
  - Total fisheries and aquaculture production
    - **China remained the major producer (36%)**, followed by India (8%), Indonesia (7%), Viet Nam (5%) and Peru (3%).
  - World capture fisheries
    - **China remained the top capture fisheries producer (14.3%)**, followed by Indonesia (8.0%), India (6.0%), Peru (5.8%), the Russian Federation (5.4%), the United States of America (4.6%), Viet Nam (3.9%) and Japan (3.2%).
  - China **shifts from being a net exporter to a net importer** of aquatic animal products **in value terms** (FAO, 2024)

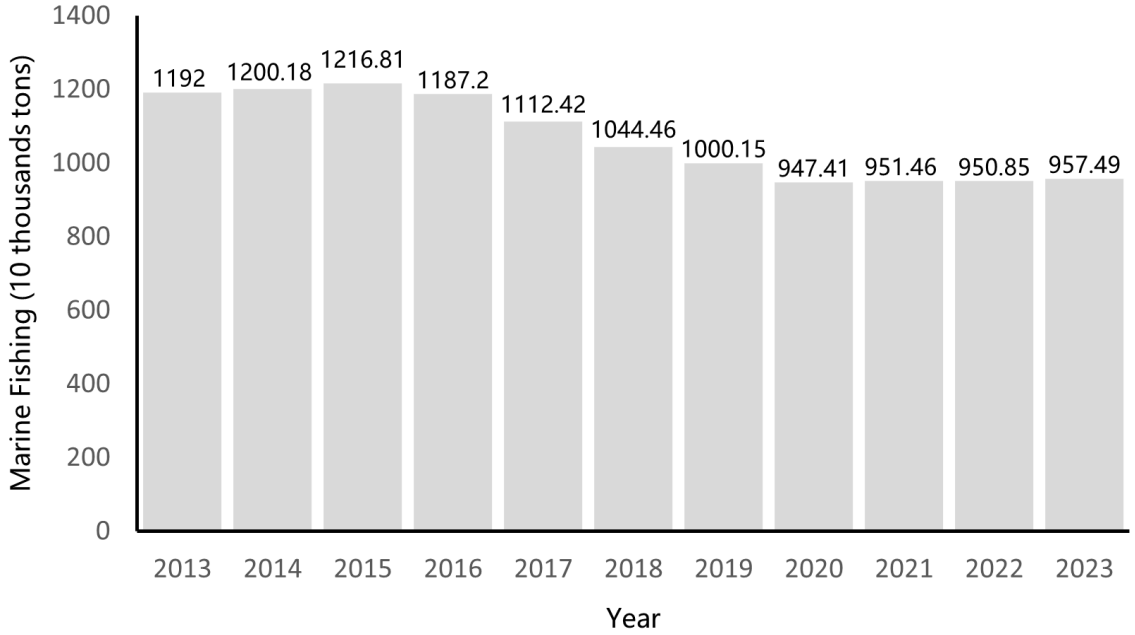




Background: China

- Overfishing? (Ministry of Agriculture of the PRC, 2024)
  - Maximum sustainable (ton/year): 8-9 or 10 million
  - Quality and quantity both affected (Liu, 2019)
  - **Summer moratorium** since 1995
  - Ten-year **fishing ban** in Yangtze River since Jan 1, 2021

- Catch-Quota Management Regimes
  - Common Pool (CP, 集体限额捕捞制度)
    - Total allowable catch
    - Total harvest:
      - 《农业部关于进一步加强国内渔船管控 实施海洋渔业资源总量管理制度的通知》（农渔发〔2017〕2号）
      - 《渔业捕捞许可管理规定》（农业农村部令2018年第1号）
    - Specific category: provincial pilots
      - Liaoning, Shandong, Zhejiang, Fujian, Guangdong
  - Individual Quota (IQ, 个人限额捕捞制度)
    - Not really in China, but adopted in Iceland, U.S., etc.



Source: China Fishery Statistical Yearbook

Background: Catch-Quota Management Regimes

- Evidence on **positive effects**
  - Chu (2009): Stocks increase in 12 out of 20 regions under **IQ**
  - Costello et al. (2008): **IQ** reduces the risk of stock collapse
  - Essington (2010): Harvesting efforts are allocated more evenly under **IQ** in North America
  - Solís et al. (2014): **IFQ** impoves the technical efficiency of commercial fleets

- But not all positive **if used not appropriately**
  - Chu (2009): Stocks in 8 regions continued to decline after implementing **IQ**
  - Pinkerton and Edwards (2009): low incentives for quota-owning vessels to maintain or increase efficiency after the first wave of consolidation
  - Pinkerton (2011): Failure to fully embrace economic, social and institutional considerations into the management system → Economic and social costs
  - Hanzawa et al. (2023): Japanese **IQ** system prohibits the selling of quotas and struggles to balance social equity and economic efficiency

- **IQ *vs*. CP**: An emerging trend allows different groups of harvesters to manage their effort using different rules and allows the concurrent rules to evolve endogenously
  - **Anderson and Uchida (2014), Wakamatsu and Anderson (2018)**
  - But only with ***homogeneous*** harvesters and ***no uncertainty*** in fish stocks

Motivation

- Two important factors in catch-quota management regimes
  - **Heterogeneity of harvesting capacity**
    - Theoretically: Heaps (2002)
    - Empirically: Johnson and Libecap (1982), Squires et al. (1995), Castello et al. (2013)
  - **Uncertainty in fish stocks**
    - Theoretically: Bockstael and Opaluch (1983), Roughgarden and Smith (1996), Weitzman (2002), Sethi et al. (2005), Valcic (2009)
    - Empirically: Holland (2008), Punt and Day (2018), Ashrafi et al. (2021), Li et al. (2021)
- This experiment extends Anderson and Uchida (2014) by including
  - Heterogeneity of harvesting capacity
  - Uncertainty in fish stocks

Theoretical Model (Anderson and Uchida, 2014)

In a group of N fishermen, fisherman i 's task is to

fish price

cost of harvesting e_{it} efforts (days)

$$\max_{e_{it}} \sum_{t=1}^{T_{max}} [(a - b * \sum_{j \in S} h_{jt}) * h_{it} - c(e_{it})] \text{ s.t. } 0 \leq e_{it} \leq e_{max}$$

effort

actual harvest

(depending on effort, harvesting capacity, management regimes and fish stock)

- Target: total allowable catch $\leq \bar{q} * N$ (cap on the total catch)
- Management regimes: m ($0 \leq m \leq N$) fishermen under CP, others under IQ
- Fishermen under CP have a total allowable catch of $m*\bar{q}$
- Every fisherman under IQ has an allowable catch of $\bar{q}$

Theoretical Model

If fisherman i is under CP:

$$h_{it} = \begin{cases} e_{it} * \overline{h_{it}} & if \quad CPH_t < \bar{q} * m \\ \dfrac{e_{it}}{E_t} * (\bar{q} * m - CPH_{t-1}) & if \quad CPH_{t-1} < \bar{q} * m \leq CPH_t \\ 0 & if \quad \bar{q} * m \leq CPH_{t-1} \end{cases}$$

If fisherman i is under IQ:

$$h_{it} = \begin{cases} e_{it} * \overline{h_{it}} & if \quad IQH_{it} < \bar{q} \\ \bar{q} - IQH_{i,\,t-1} & if \quad IQH_{i,\,t-1} < \bar{q} \leq IQH_{it} \\ 0 & if \quad \bar{q} \leq IQH_{i,\,t-1} \end{cases}$$

where $\boldsymbol{CPH_t} = \sum_{j \in S_{CP}, k \leq t} e_{jk} * \overline{h_{jk}}$, $\boldsymbol{IQH_{it}} = \sum_{k \leq t} e_{ik} * \overline{h_{ik}}$, and

$\overline{\boldsymbol{h_{it}}}$: *i*'s harvest per unit effort in week *t*, depending on *i*'s harvesting capacity and week *t*'s fish stock

Experimental Design (*c.f.* Anderson & Uchida 2014)

Parameters

Variable	Definition	Value
N	Number of fishermen	12
$\boldsymbol{m}$	**Number of fishermen under CP**	$\boldsymbol{0 \leq m \leq N}$**,** **depending on the regimes**
T_{max}	Number of weeks in one year	52
$\bar{q}$	Total allowable catch / N	3000
e_{max}	Maximum effort level (days) per week	7
$c(e_{it})$	Cost function	$500 * e_{it}$
$\boldsymbol{\overline{h_{it}}}$	**i's harvest per unit effort in week t**	**depending on i's harvesting capacity and fish stock**
a	A parameter in market demand function: $p_t = a - b * \sum_{i \in S} h_{it}$	50
b	A parameter in market demand function: $p_t = a - b * \sum_{i \in S} h_{it}$	0.012

Experimental Design

4 different management regimes: different m $(0 \leq m \leq N)$

1) CP: $m = N$
2) IQ: $m = 0$
3) MIXED: $m = N/2$
4) **CHOICE: 2 stages in every year**
   - **1st stage: every subject decides which management regime he/she prefers**
   - **2nd stage: subjects play the fishery simulation game under the regimes they choose**

3 fishery scenarios: different $\overline{h_{it}}$

- Baseline game (Anderson and Uchida, 2014): $\overline{h_{it}} = 30$
- Heterogeneity of harvesting capacity (HETERO):
- $$\overline{h_{it}} = \begin{cases} 20 & i \in low\ \ capacity\ (9\ subjects) \\ 60 & i \in high\ \ capacity\ (3\ subjects) \end{cases}$$
- Uncertain fish stocks: $\overline{h_{it}} = \bar{h}_t$, uniformly distributed on [15, 45]

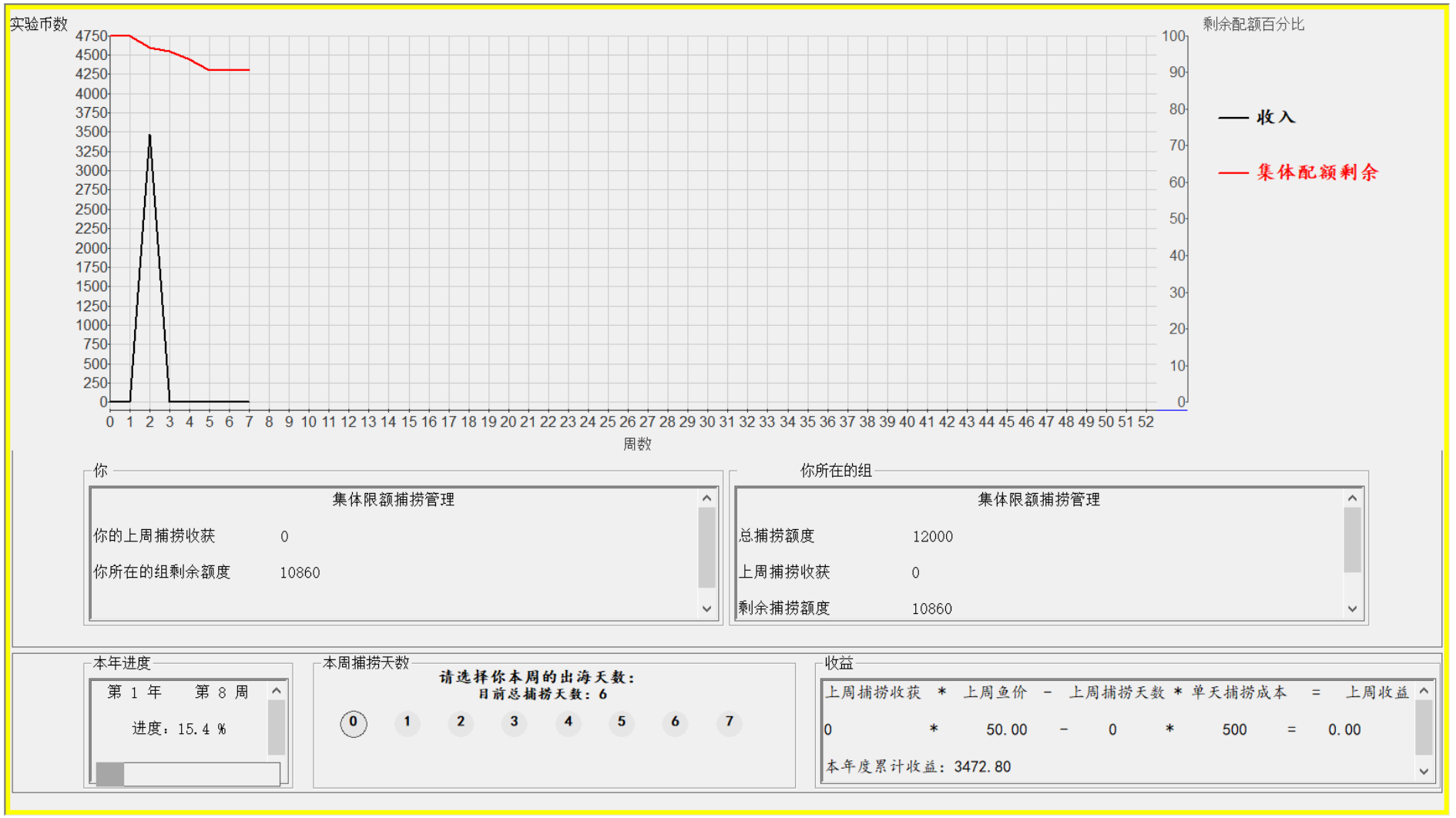
Experimental Design

- 1 round = 1 year = 52 weeks
- 4 seconds for each subject to make a decision in each week
- 144 subjects = 2*12 subjects/session * 6 session

Treatment Design

Rounds 1-3	Rounds 4-6	Rounds 7-10	Rounds 11-20	# of subjects per session	# of sessions
CP-Baseline	IQ-Baseline	MIXED-Baseline	CHOICE-Baseline	12	2
IQ-Baseline	CP-Baseline	MIXED-Baseline	CHOICE-Baseline	12	2
CP-HETERO	IQ-HETERO	MIXED-HETERO	CHOICE-HETERO	12	2
IQ-HETERO	CP-HETERO	MIXED-HETERO	CHOICE-HETERO	12	2
CP-UNCERTAIN	IQ-UNCERTAIN	MIXED-UNCERTAIN	CHOICE-UNCERTAIN	12	2
IQ-UNCERTAIN	CP-UNCERTAIN	MIXED-UNCERTAIN	CHOICE-UNCERTAIN	12	2

Experimental Design: Interface



Hypotheses: All CP and All IQ

Treatment		Weeks	Mean Nash Days	Nash Profit
Baseline	All CP			
	12 CP	1-14	7	10576
		15	2	
		16-52	Closed	
	All IQ			
	12 IQ	1-52	1.92	75077
HETERO	All CP			
	3 HIGH	1-18	7	133560
		19-52	Closed	
	9 LOW	1-18	4.11	1480
		19-52	Closed	
	All IQ			
	3 HIGH	1-52	0.96	100077
	9 LOW	1-52	2.88	50077
UNCERTAIN	All CP			
	12 CP	1-14	7	10576
		15	2	
		16-52	Closed	
	All IQ			
	12 IQ	1-52	1.92	75077

1. **CP** → shorter fishing periods;
   IQ → longer fishing periods

2. **HETERO under CP:**
high capacity → race to fish
low capacity → lower efforts

3. **HETERO w.r.t income gap;**
CP → larger income gap;
IQ→ smaller income gap**.**

4. **UNCERTAIN:**
same as the baseline in expectation

Hypotheses: CHOICE

In all treatments

Nash Equilibrium of CHOICE:

- 1st stage: All subjects choose IQ
- 2nd stage: All subjects follow the NE strategy under IQ

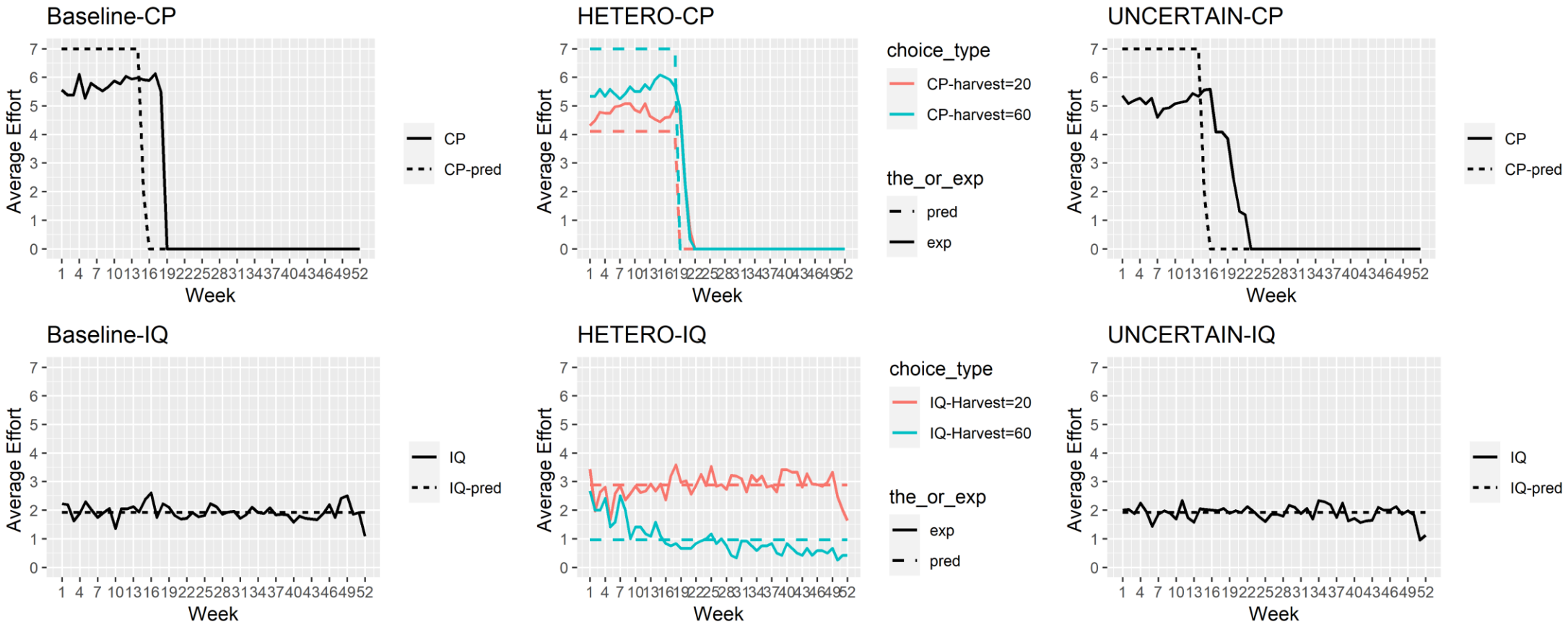
Results

1. Comparisons among treatments
2. Decision-making in CHOICE

Allocation of Harvesting Efforts

BASELINE (no hetero, no uncertainty)**: consistent with Anderson and Uchida (2014)**

CP→ race to fish, shorter fishing periods; IQ→ evenly distributed, longer fishing periods

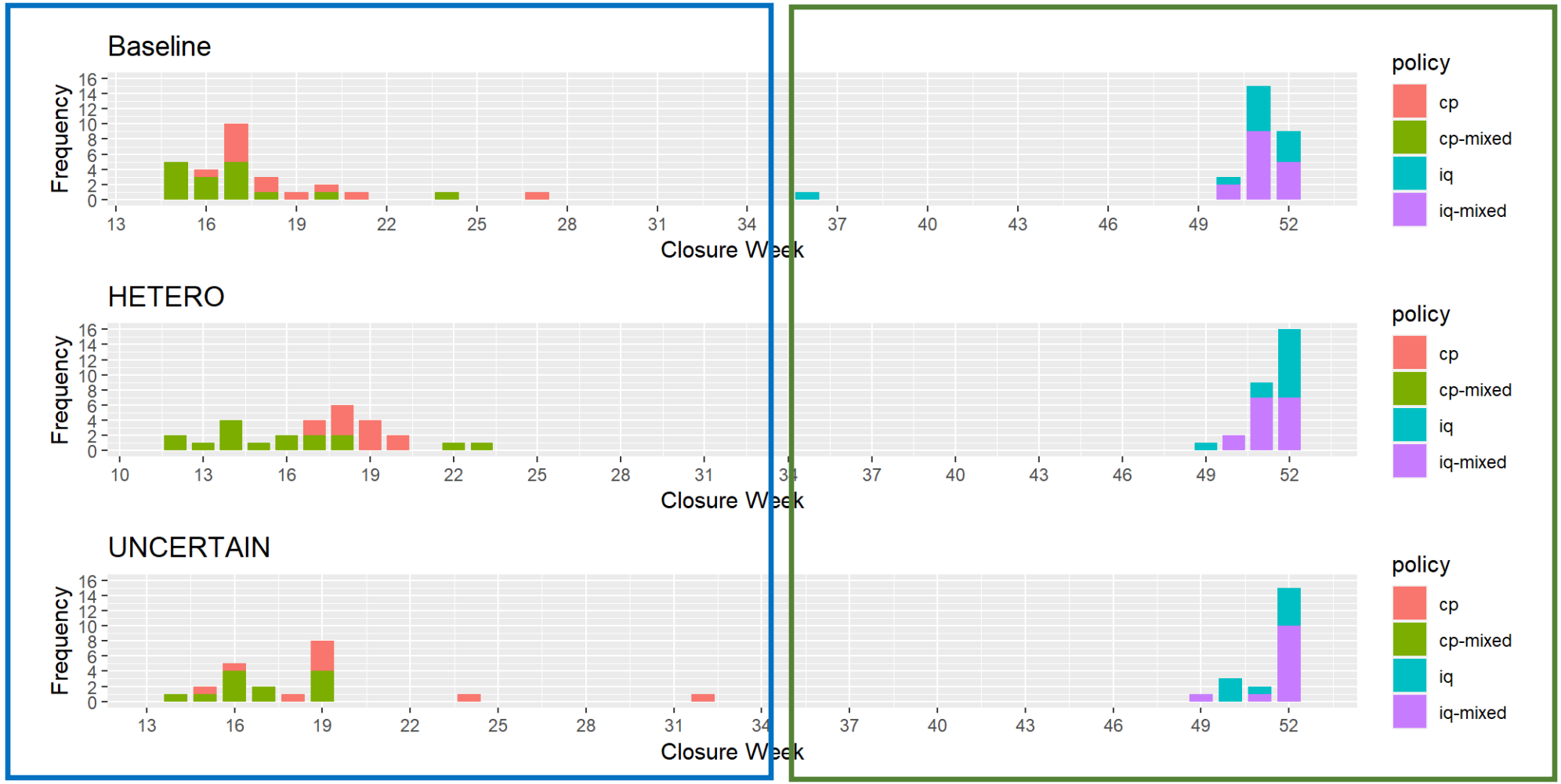


Length of Fishing Periods

BASELINE (no hetero, no uncertainty)**: consistent with Anderson and Uchida (2014)**

CP→ race to fish, shorter fishing periods; IQ→ evenly distributed, longer fishing periods

CP

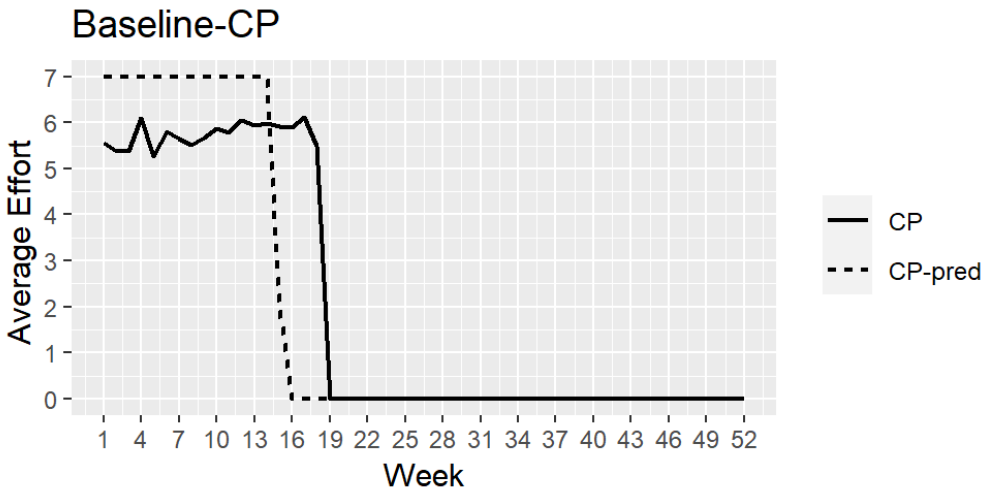


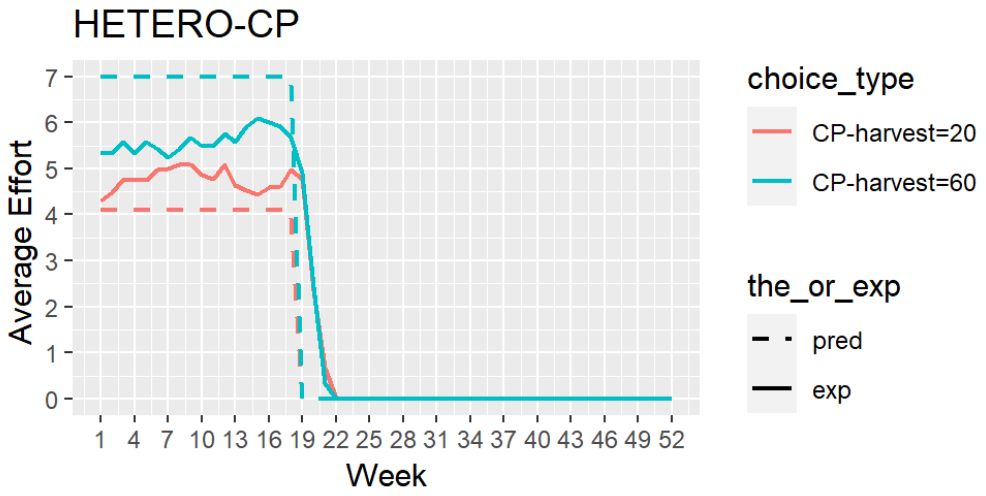
IQ

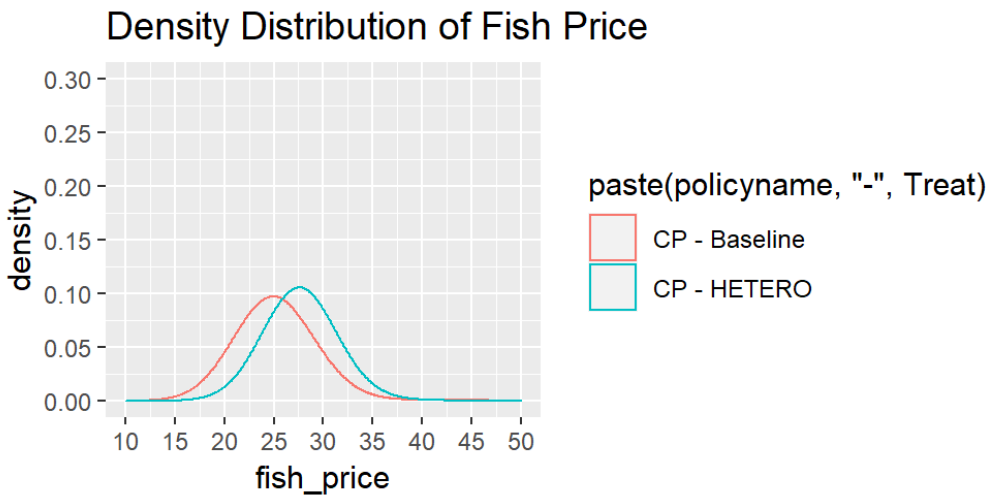
Introducing HETERO

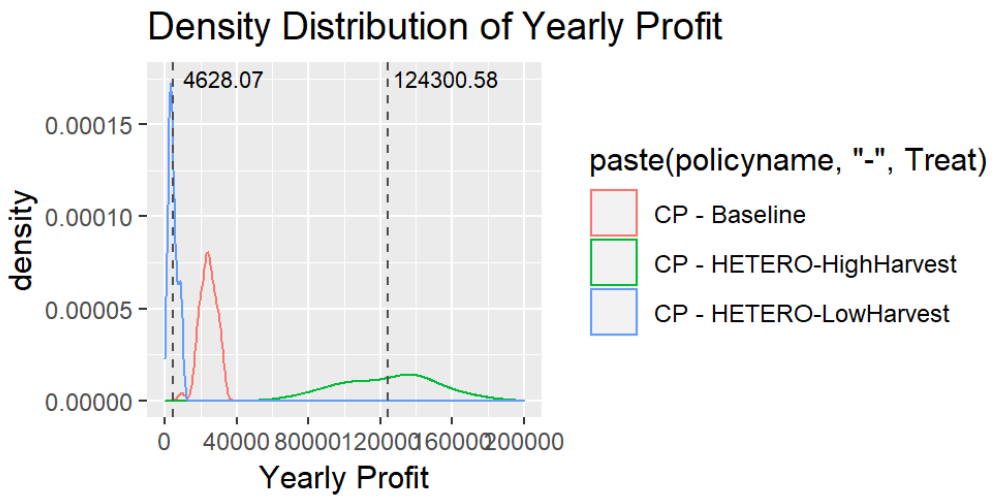
Effects of HETERO in CP

HETERO→ low capacity's effort ↓, fish price↑ → large income gaps



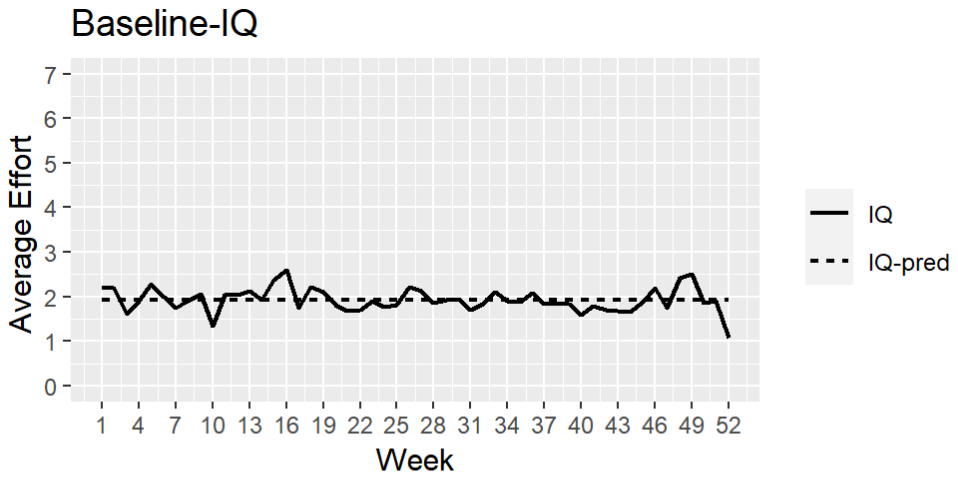


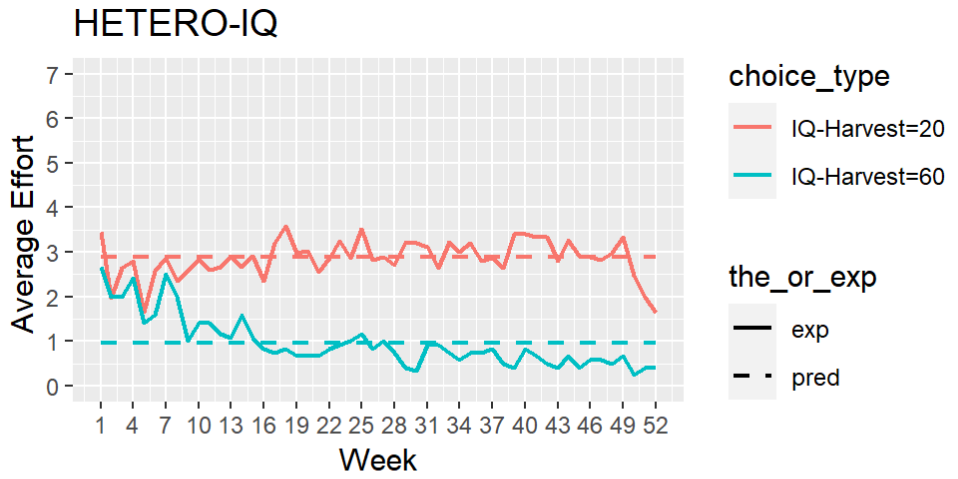


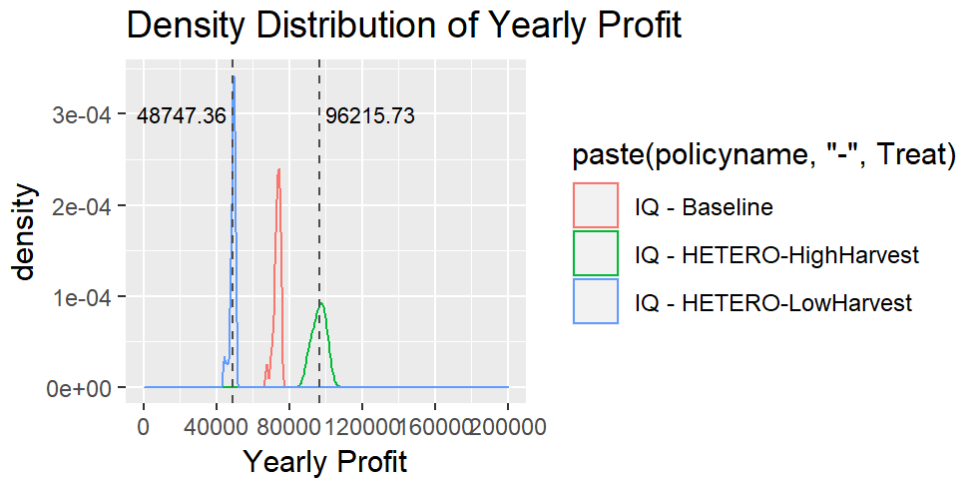


Effects of HETERO in IQ

HETERO→ still evenly distributed efforts, no price difference, narrower income gaps

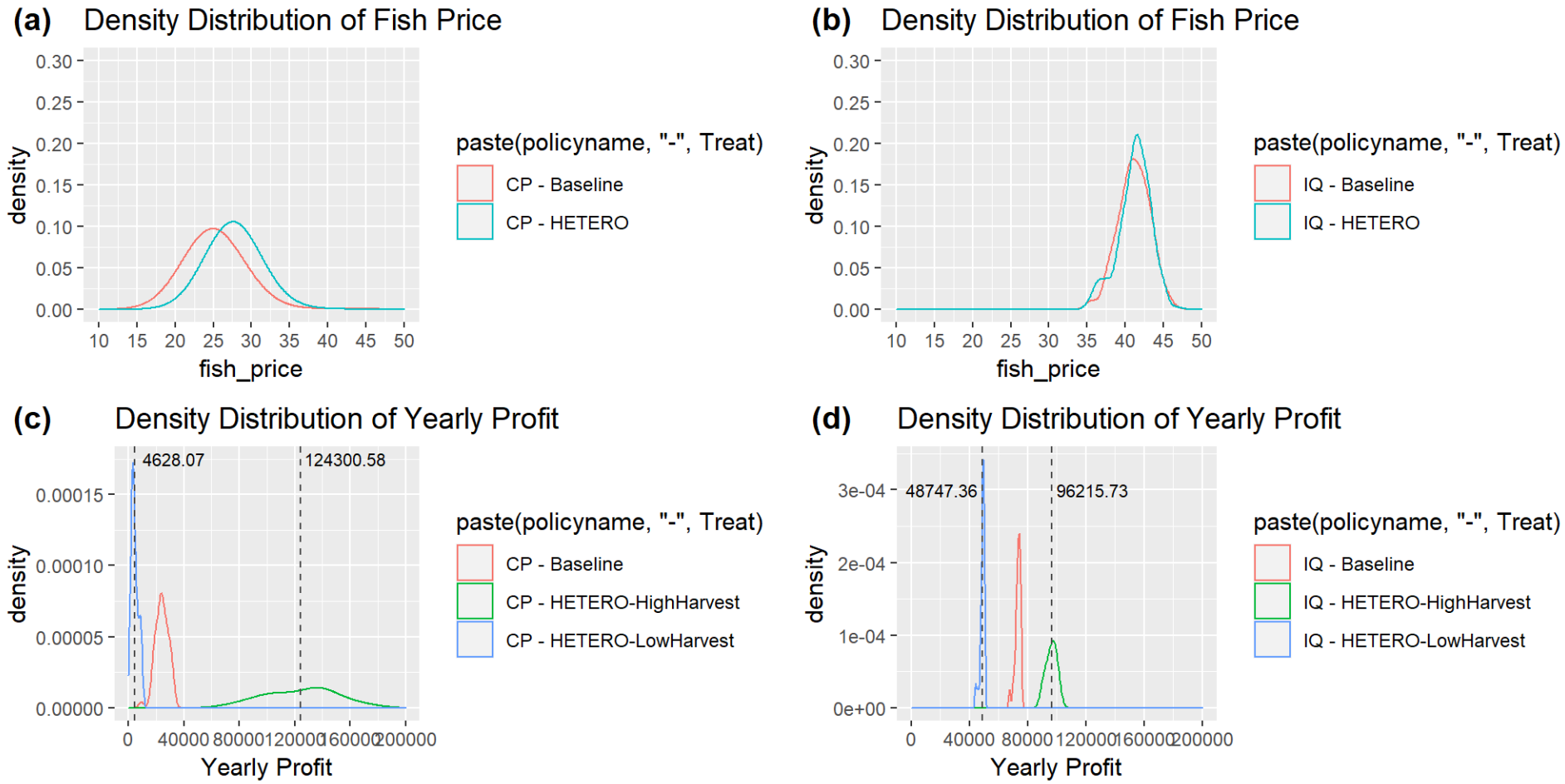






HETERO: CP vs. IQ

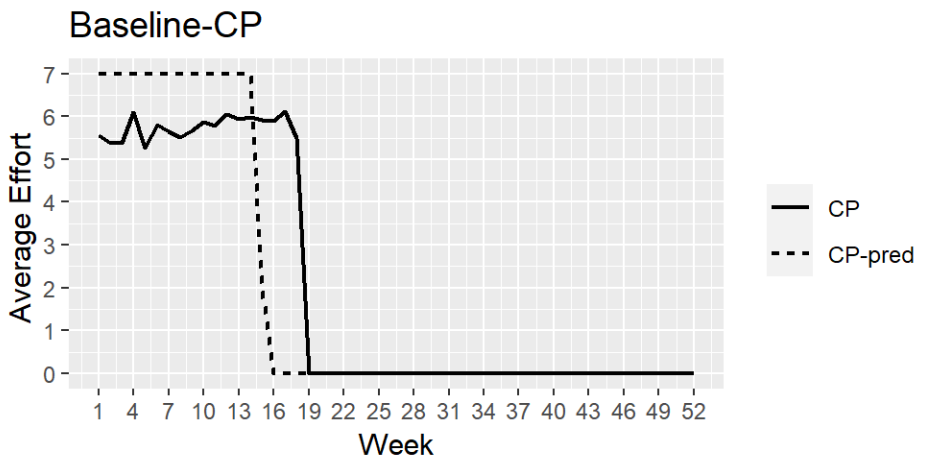
IQ→ larger social welfare, protecting low capacity harvesters, narrower income gap

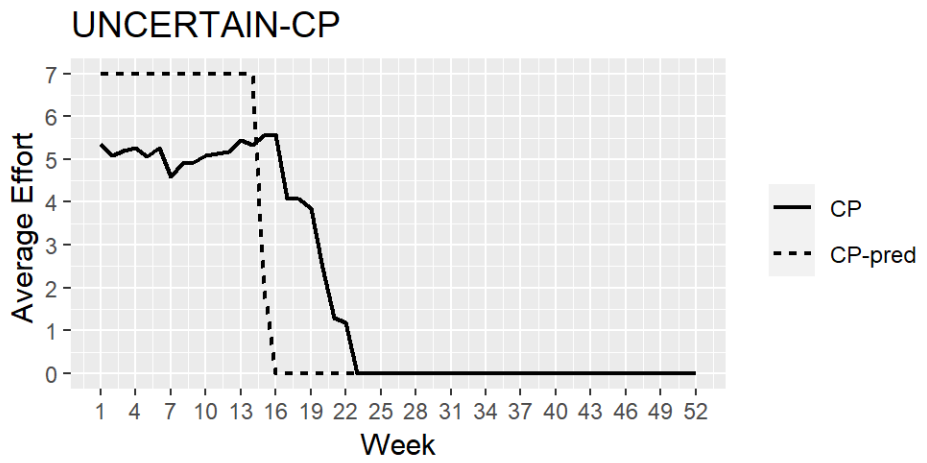


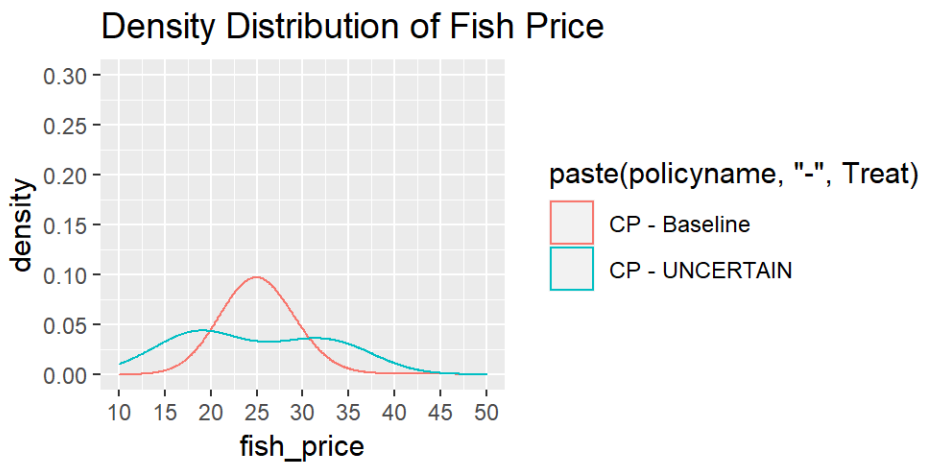
Introducing UNCERTAINTY

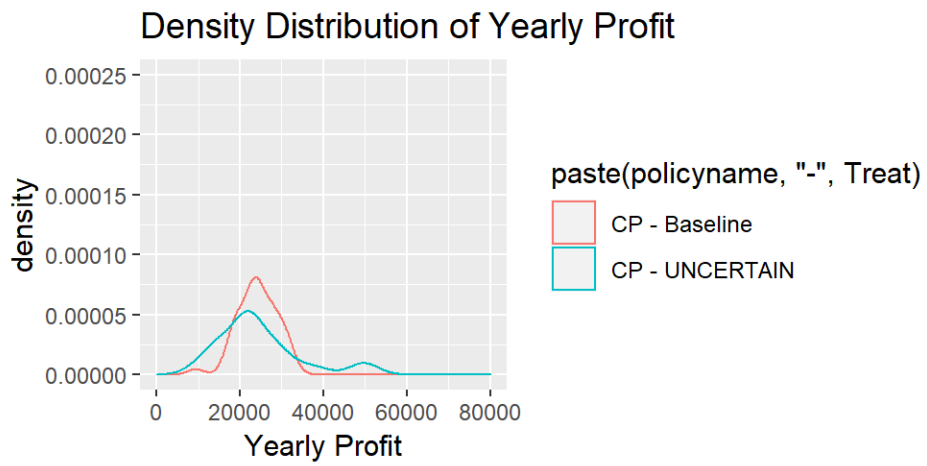
Effects of UNCERTAINTY in CP

STOCK UNCERTAINTY→ fishing periods ↑, price volatility ↑



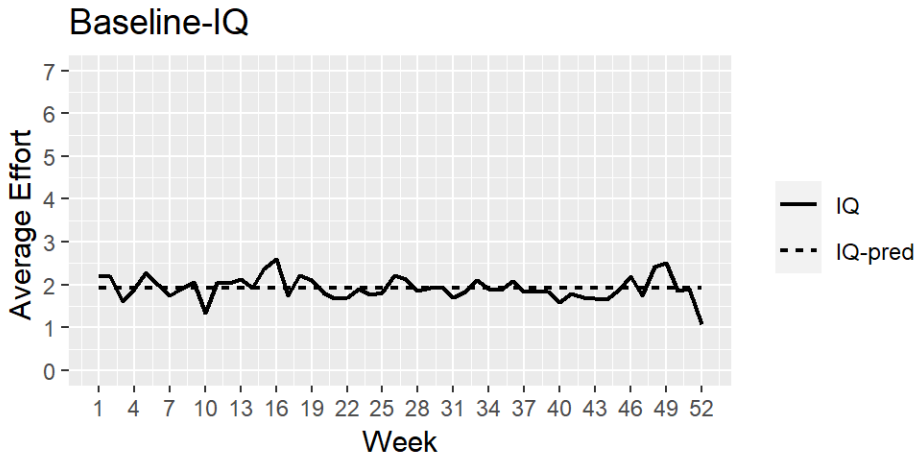


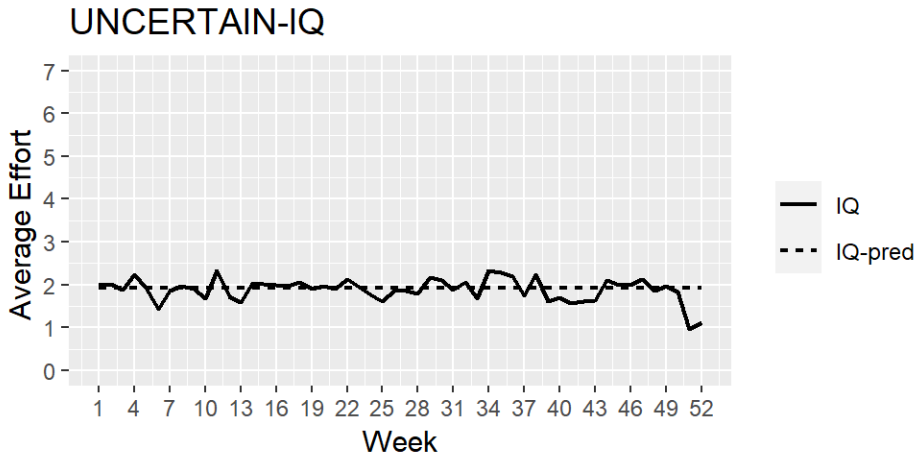


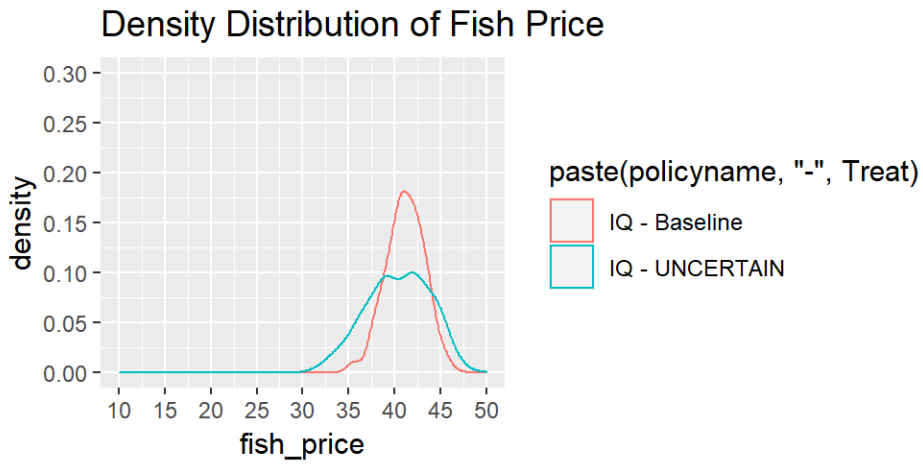


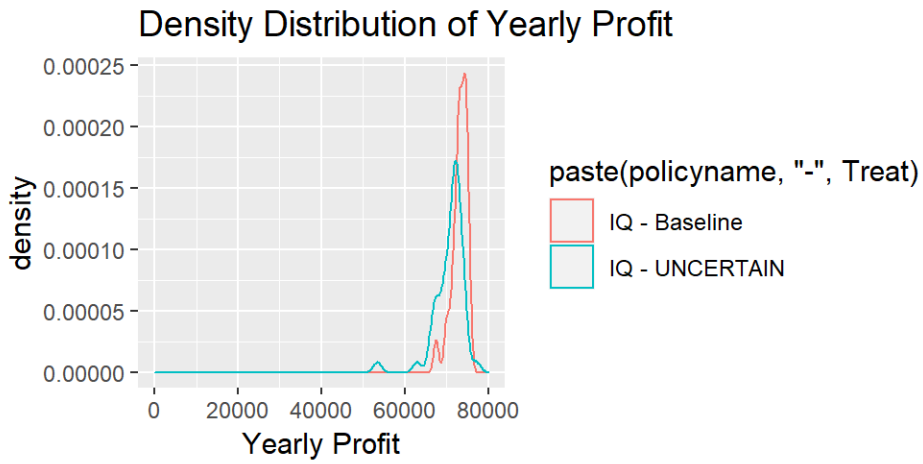
Effects of UNCERTAINTY in IQ

STOCK UNCERTAINTY → income variance↑



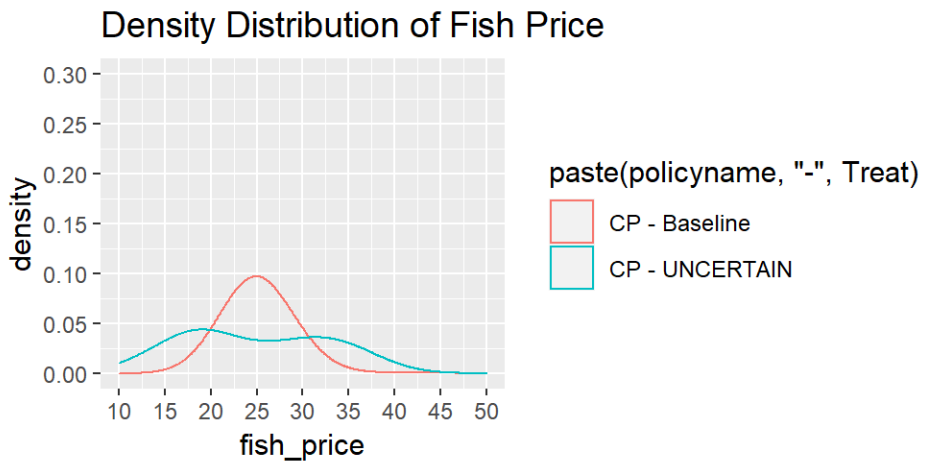


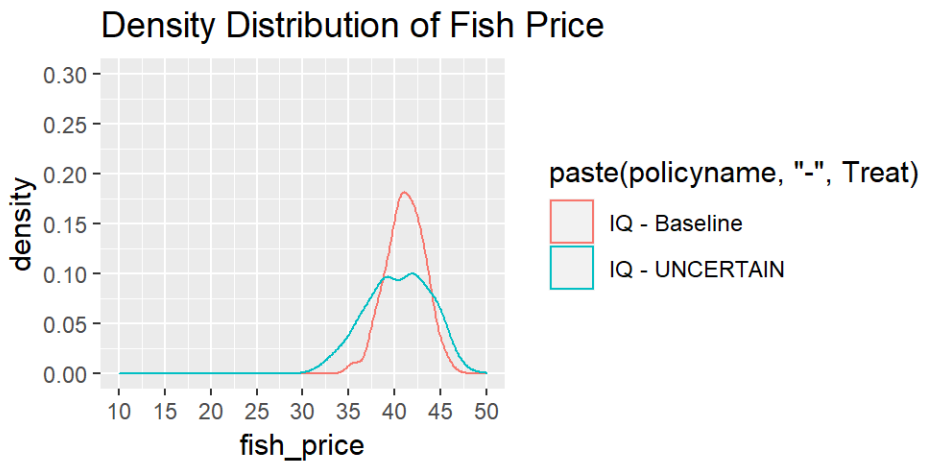


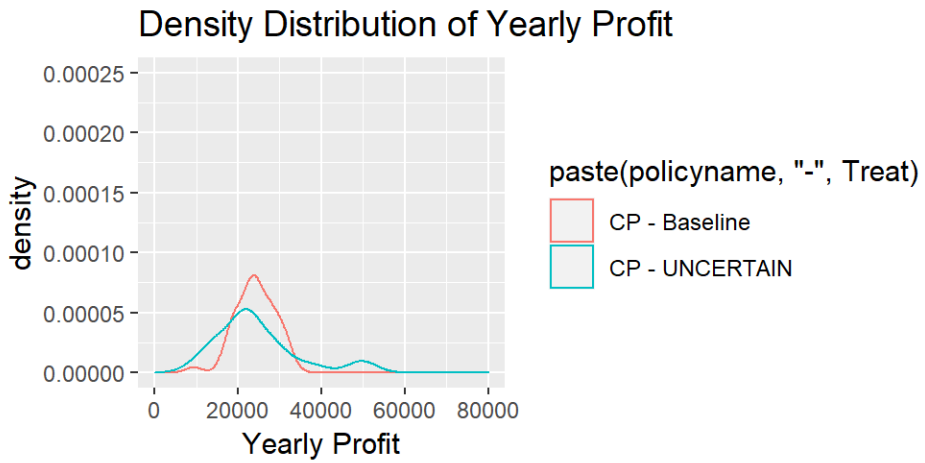


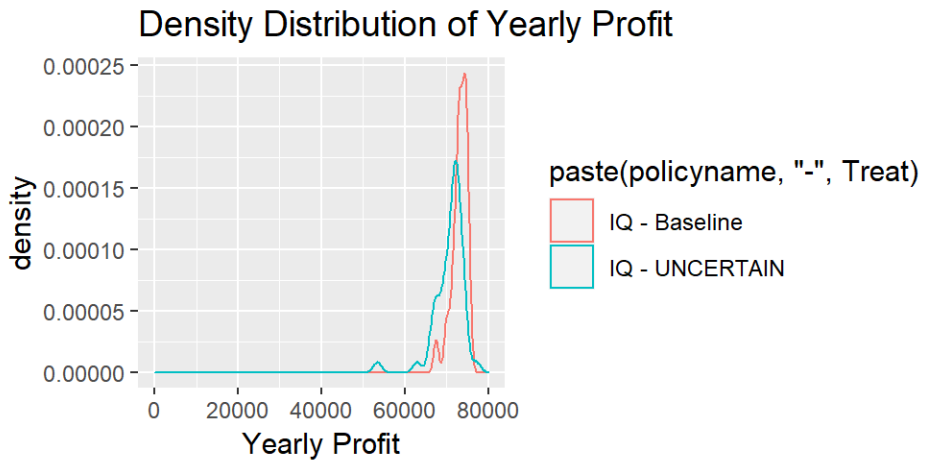
UNCERTAINTY : CP vs. IQ

IQ → smaller variances in prices and profits



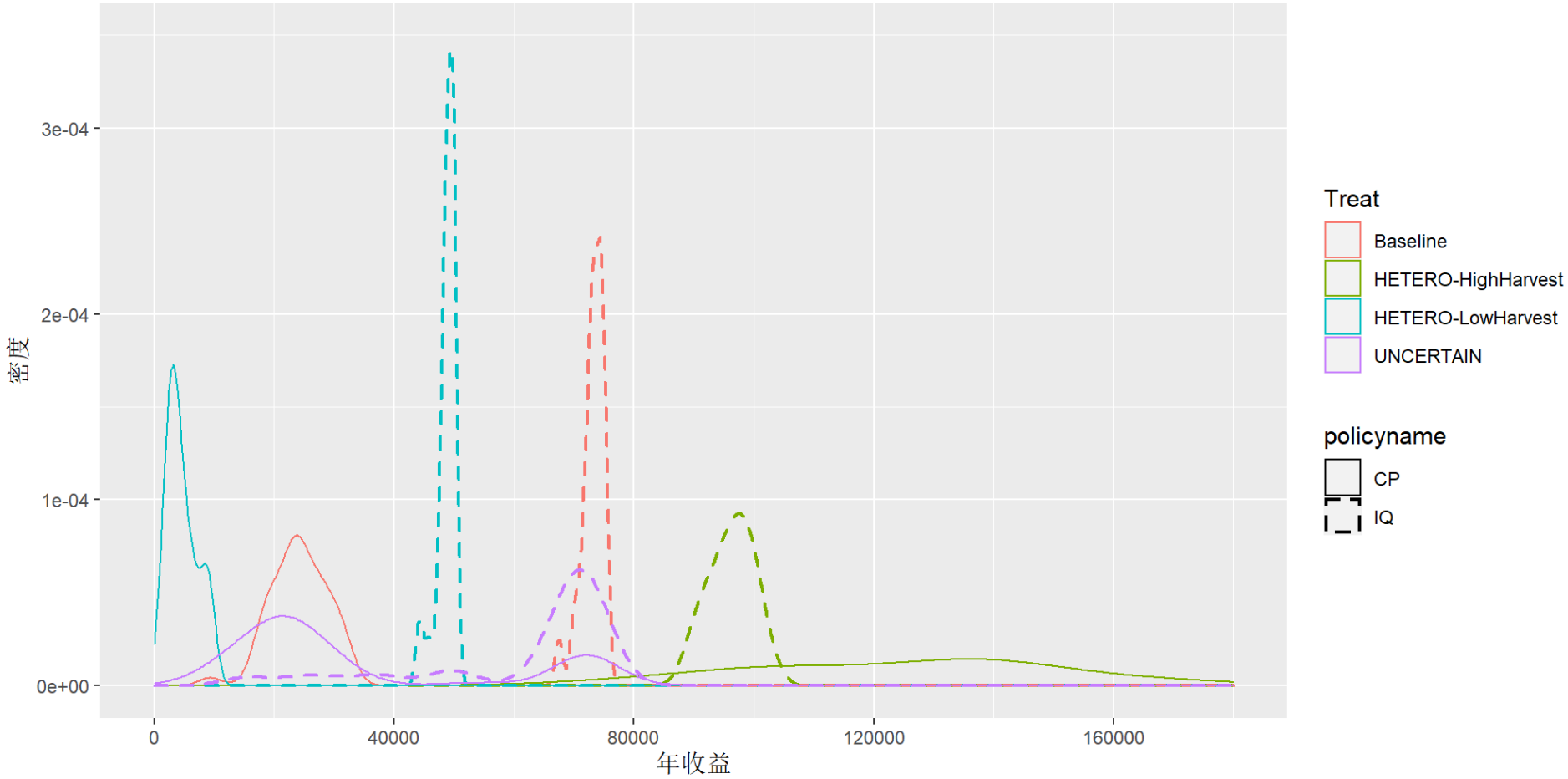






Average income: CP vs. IQ

CP-HETERO-low capacity < CP-UNCERTAIN ≈ CP-Baseline < IQ-HETERO-low capacity < IQ-UNCERTAIN < IQ-Baseline < IQ-HETERO-high capacity < CP-HETERO-high capacity



CHOICE:
Preference for CP or IQ?
Determinants?

Experimental Design

- 1 round = 1 year = 52 weeks
- 4 seconds for each subject to make a decision in each week
- 144 subjects = 2*12 subjects/session * 6 session

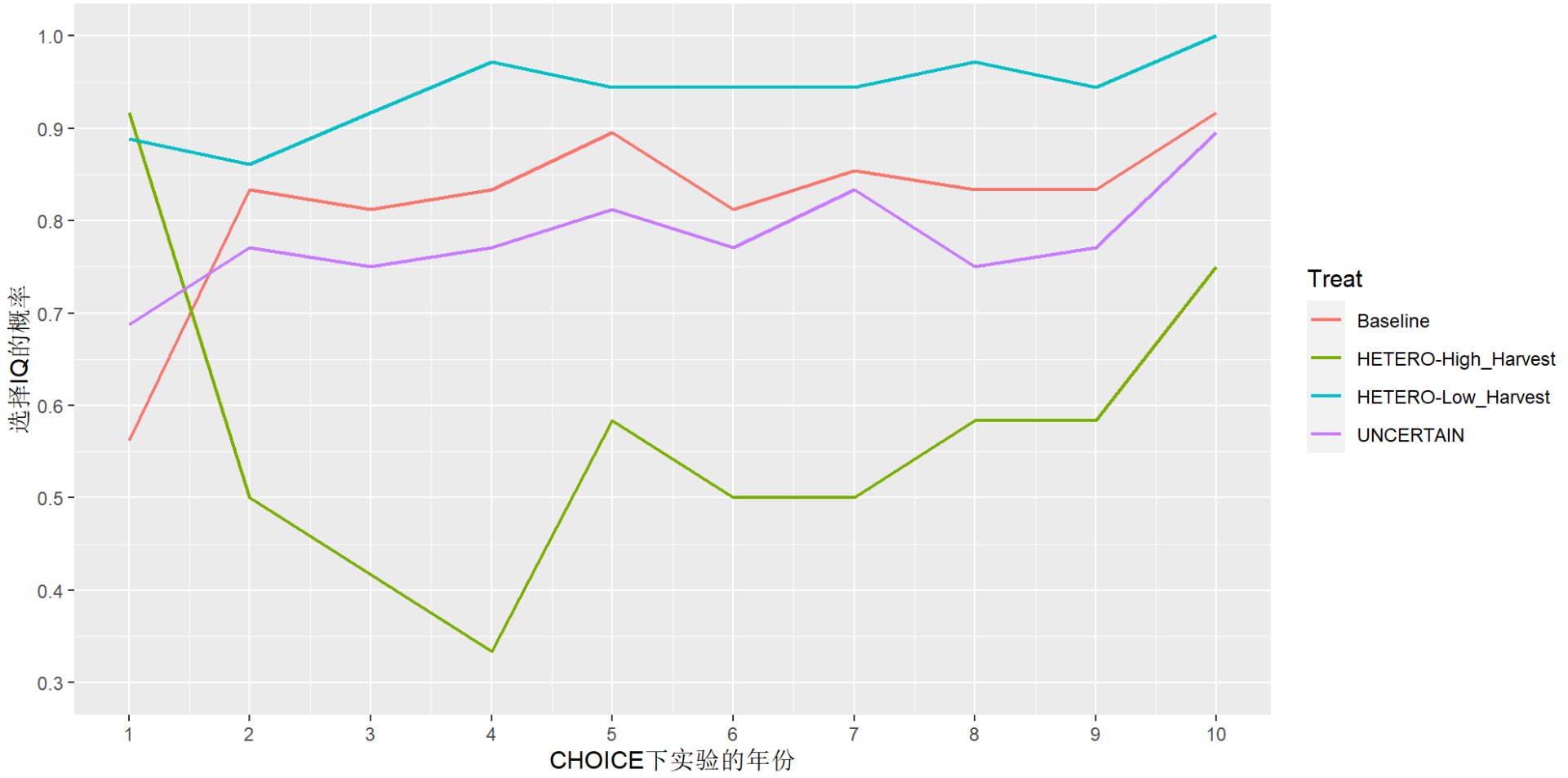
Choice of IQ in the last 10 rounds

Treatment Design

Rounds 1-3	Rounds 4-6	Rounds 7-10	Rounds 11-20	# of subjects per session	# of sessions
CP-Baseline	IQ-Baseline	MIXED-Baseline	CHOICE-Baseline	12	2
IQ-Baseline	CP-Baseline	MIXED-Baseline	CHOICE-Baseline	12	2
CP-HETERO	IQ-HETERO	MIXED-HETERO	CHOICE-HETERO	12	2
IQ-HETERO	CP-HETERO	MIXED-HETERO	CHOICE-HETERO	12	2
CP-UNCERTAIN	IQ-UNCERTAIN	MIXED-UNCERTAIN	CHOICE-UNCERTAIN	12	2
IQ-UNCERTAIN	CP-UNCERTAIN	MIXED-UNCERTAIN	CHOICE-UNCERTAIN	12	2

Percentage of choosing IQ in CHOICE

HETERO-low capacity > Baseline ≈ UNCERTAIN > HETERO-high capacity



CHOICE: Baseline

1. **Experiencing larger annual profit differences between IQ and CP induces more choices of IQ.**
2. **Risk-loving subjects are more likely to choose CP.**

Variables	(1)	(2)	(3)	(4)
Constant	-1.77	-1.69	-1.73	0.08
	(1.29)	(2.00)	(2.01)	(2.34)
LnMaxProfitDiff	0.36***	0.43**	0.43**	0.49***
	(0.13)	(0.20)	(0.20)	(0.19)
$NOthers_{t-1}$		0.05	0.05	0.05
		(0.13)	(0.13)	(0.13)
$CPover3k_{t-1}$			0.10	0.13
			(0.48)	(0.47)
Contentiousness				-0.04
				(0.11)
Risk_loving				-2.25*
				(1.22)
Dictator				-0.15
				(0.10)
N	480	432	432	432
AIC	414.9	310.4	312.4	312.6
Log Likelihood	-204.4	-151.2	-151.2	-148.3

Y: 1 if this subject choose IQ in period *t*, 0 otherwise

LnMaxProfitDiff: ln(max annual profit in IQ – max annual profit in CP)

$NOthers_{t-1}$: the number of subjects choosing IQ in t-1 period

$CPover3k_{t-1}$: 1 if harvesting more than 3000 under CP last time

Contentiousness: the level at which subjects are willing to argue with others

Risk_loving: subjects' self-evaluation of risk attitude

Dictator: the number of coins subjects decide to keep in the dictator game

CHOICE: HETERO

In HETERO, high capacity harvesters are more likely to choose CP.

Variables	(1)	(2)	(3)	(4)
Constant	3.37***	3.37**	3.35**	3.33*
	(0.37)	(1.55)	(1.68)	(1.74)
$High_t$	-2.95***	-2.84*	-3.55*	-3.73*
	(0.37)	(1.64)	(1.87)	(1.90)
MaxProfitDiff_H*10^{-5}		-0.18	-0.16	-0.22
		(1.13)	(1.16)	(1.21)
MaxProfitDiff_L*10^{-5}		0.32	-0.07	0.24
		(3.79)	(3.92)	(4.00)
MaxProfitDiff_H*$High_t$ *10^{-5}		1.33	0.82	0.90
		(1.19)	(1.25)	(1.30)
MaxProfitDiff_L*Low_t *10^{-5}		-0.94	-1.15	-1.28
		(4.02)	(4.39)	(4.42)
Control Variables				
Others' choices last year	No	No	Yes	Yes
Subjects' personality	No	No	No	Yes
N	480	290	261	261
AIC	314.6	210.6	189.4	193
Log Likelihood	-154.3	-98.3	-84.7	-84.5

Y: 1 if this subject choose IQ in period t, 0 otherwise

$High_t$: 1 if this subject has high harvesting capacity in period t

MaxProfitDiff_H: max annual profit in IQ when this subject has high harvest capacity – max annual profit in CP when this subject has high harvest capacity

MaxProfitDiff_L: max annual profit in IQ when this subject has low harvest capacity – max annual profit in CP when this subject has low harvest capacity

CHOICE: UNCERTAINTY

1. **If more subjects chose IQ in period t-1, subjects in period t are more likely to choose IQ.**
2. **Subjects who harvested more than 3000 under CP last time are more likely to choose CP.**

Variables	(1)	(2)	(3)	(4)
Constant	1.78***	1.09**	1.42***	1.35
	(0.40)	(0.53)	(0.55)	(1.71)
MaxProfitDiff*10^{-5}	1.13	1.03	0.43	-0.98
	(1.79)	(1.87)	(1.85)	(2.10)
NOthers $_{t-1}$		0.35***	0.39***	0.39***
		(0.13)	(0.14)	(0.14)
CPover3k $_{t-1}$			-0.81**	-0.85**
			(0.40)	(0.40)
risk_loving				-0.20
				(1.18)
dictator				-0.05
				(0.09)
Competitiveness				0.09
				(0.06)
N	480	432	432	432
AIC	440.2	381.4	379.2	382.8
Log Likelihood	-217.1	-186.7	-184.6	-183.4

Y: 1 if this subject choose IQ in period t, 0 otherwise

MaxProfitDiff: max annual profit in IQ – max annual profit in CP

NOthers$_{t-1}$: the number of subjects choosing IQ in t-1 period

CPover3k$_{t-1}$: 1 if this subjects harvest more than 3000 under CP last time

Risk_loving: subjects' self-evaluation of risk attitude

Dictator: the number of coins subjects decide to keep in the dictator game

Competitiveness: the level at which this subject enjoys competing with others

Conclusion

1. Heterogeneity in harvesting capacity
   - CP: discourage low capacity's efforts, overall lower price & larger income gaps
   - IQ: protect low capacity harvesters, overall higher price, profits & narrower income gaps
   - CHOICE: low-capacity prefers IQ; high-capacity chooses IQ less
2. Uncertainty in fish stocks
   - Larger variances in price and income, but relatively smaller in IQ
3. Comparisons of the two catch-quota management regimes
   - IQ may be preferred
     - a more stable market (longer supply periods) with a relatively higher price
     - low capacity harvesters are protected with a lower income inequality
     - smaller variances in prices and profits with uncertain fish stocks

Thank you!

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