The Role of Information and Monitoring on Collusion

Christian Rojas
University of Massachusetts Amherst

Motivation

1. Stylized IO facts on factors affecting collusion:
   - **Monitoring** of cartel members (Stigler)
   - **Demand information** (Tirole)

2. Well-known theories inform our design:
   - Green and Porter (1984), GP
     - Finite price wars triggered by low demand
     - Collusion more stable when demand is high
   - Rotemberg and Saloner (1986), RS
     - Price wars observed in high demand
     - Collusion more stable during low demand

3. Collusion is one of several equilibria. Which predictions are more plausible?

4. Assumptions difficult to control, data difficult to get

Theory: Assumptions

- Homogenous products
- Cournot competition
- Symmetric firms and constant MC
- Infinitely repeated game
- *Stochastic* (uncertain) demand
  - RS:
    - Uncertain future demand, *except* for t+1 (tomorrow),
    - **Perfect monitoring** and **perfect information on** "(t+1)"
  - GP:
    - Uncertainty for all future (and past) demand schedules
    - **Imperfect monitoring** and **imperfect information**

Theory: RS Equilibrium

- Demand is stochastic but we all know that tomorrow is "Christmas"
- For a large enough demand shock:

$$\Pi_{high}^{D} - \Pi_{high}^{C} > \frac{\delta}{1-\delta} E(\Pi_i^C - \Pi_i^{NE})$$

- Collusion is more feasible in "bad times"

$$\Pi_{low}^{D} - \Pi_{low}^{C} < \frac{\delta}{1-\delta} E(\Pi_i^C - \Pi_i^{NE})$$

- Grim-trigger strategy is assumed (but not necessary)
- Other equilibria, e.g. always defect

Theory: GP Equilibrium

- Imperfect monitoring: low profit caused by
  - Low demand, or
  - Rival's defection
- Equilibrium:
  - "Mafia-like": punishment (finite price war) necessary beyond some suspicion (e.g. price) level.
  - No cheating: low profit only caused by large negative demand shock
    - Length of punishment (N*) set to offset gains from cheating
  - Other equilibria: always defect, longer punishment lengths [N*,∞]

Experimental Design

- Two Quantity choices (L, H), prisoner's dilemma
- 3 Demand states (three payoff matrices):
  - *high* (20%) - *h*
  - *medium* (60%) - *m*
  - *low* (20%) - *l*
- 30 rounds, then game ends with 25% probability
- 3 treatments:
  - FI: demand information + perfect monitoring (RS)
  - M: perfect monitoring
  - IM: imperfect monitoring (GP)

Round

1

Remaining Time [45]: 27

Probability of Playing the **Red** Game this Round is **20%**

20%	Other Player's Choice is "A"	Other Player's Choice is "B"
Your Choice is **"A"**	26.00 , 26.00	7.50 , 43.00
Your Choice is **"B"**	43.00 , 7.50	12.50 , 12.50

Probability of Playing the **GREEN** Game this Round is **60%**

60%	Other Player's Choice is "A"	Other Player's Choice is "B"
Your Choice is **"A"**	7.50 , 7.50	2.10 , 12.50
Your Choice is **"B"**	12.50 , 2.10	3.50 , 3.50

Probability of Playing the **BLUE** Game this Round is **20%**

20%	Other Player's Choice is "A"	Other Player's Choice is "B"
Your Choice is **"A"**	2.10 , 2.10	0.60 , 3.50
Your Choice is **"B"**	3.50 , 0.60	1.00 , 1.00

Chance has determined that you will play the "GREEN" game

	Other Player's Choice is "A"	Other Player's Choice is "B"
Your Choice is **"A"**	7.50 , 7.50	2.10 , 12.50
Your Choice is **"B"**	12.50 , 2.10	3.50 , 3.50

Your Choice ○ A ○ B

OK

History Table

Round

1

20%	Other Player's Choice is "A"	Other Player's Choice is "B"
Your Choice is "A"	26.00 , 26.00	7.50 , 43.00
Your Choice is "B"	43.00 , 7.50	12.50 , 12.50

60%	Other Player's Choice is "A"	Other Player's Choice is "B"
Your Choice is "A"	7.50 , 7.50	2.10 , 12.50
Your Choice is "B"	12.50 , 2.10	3.50 , 3.50

20%	Other Player's Choice is "A"	Other Player's Choice is "B"
Your Choice is "A"	2.10 , 2.10	0.60 , 3.50
Your Choice is "B"	3.50 , 0.60	1.00 , 1.00

Chance has determined that you will play the "GREEN" game:

The Results of the Round are:

	Other Player's Choice was "A"	
Your Choice was "B"	12.50 , 2.10	

Your Earnings for this Period are E$ 12.50

Continue

Round

1

Remaining Time [45]: 20

Probability of Playing the **Red** Game this Round is **20%**

20%	Other Player's Choice is "A"	Other Player's Choice is "B"
Your Choice is **"A"**	26.00 , 26.00	7.50 , 43.00
Your Choice is **"B"**	43.00 , 7.50	12.50 , 12.50

Probability of Playing the **GREEN** Game this Round is **60%**

60%	Other Player's Choice is "A"	Other Player's Choice is "B"
Your Choice is **"A"**	7.50 , 7.50	2.10 , 12.50
Your Choice is **"B"**	12.50 , 2.10	3.50 , 3.50

Probability of Playing the **BLUE** Game this Round is **20%**

20%	Other Player's Choice is "A"	Other Player's Choice is "B"
Your Choice is **"A"**	2.10 , 2.10	0.60 , 3.50
Your Choice is **"B"**	3.50 , 0.60	1.00 , 1.00

Please choose the strategy you would like to play for this round:

- A
- B

OK

History Table

Round

1

20%	Other Player's Choice is "A"	Other Player's Choice is "B"
Your Choice is "A"	26.00 , 26.00	7.50 , 43.00
Your Choice is "B"	43.00 , 7.50	12.50 , 12.50

60%	Other Player's Choice is "A"	Other Player's Choice is "B"
Your Choice is "A"	7.50 , 7.50	2.10 , 12.50
Your Choice is "B"	12.50 , 2.10	3.50 , 3.50

20%	Other Player's Choice is "A"	Other Player's Choice is "B"
Your Choice is "A"	2.10 , 2.10	0.60 , 3.50
Your Choice is "B"	3.50 , 0.60	1.00 , 1.00

After the computer has chosen a game and your counterpart has chosen a strategy, the Results of this Second Practice Round are:

Your Earnings for this Period in E$ 12.50

Continue

The possible outcomes for this round are:

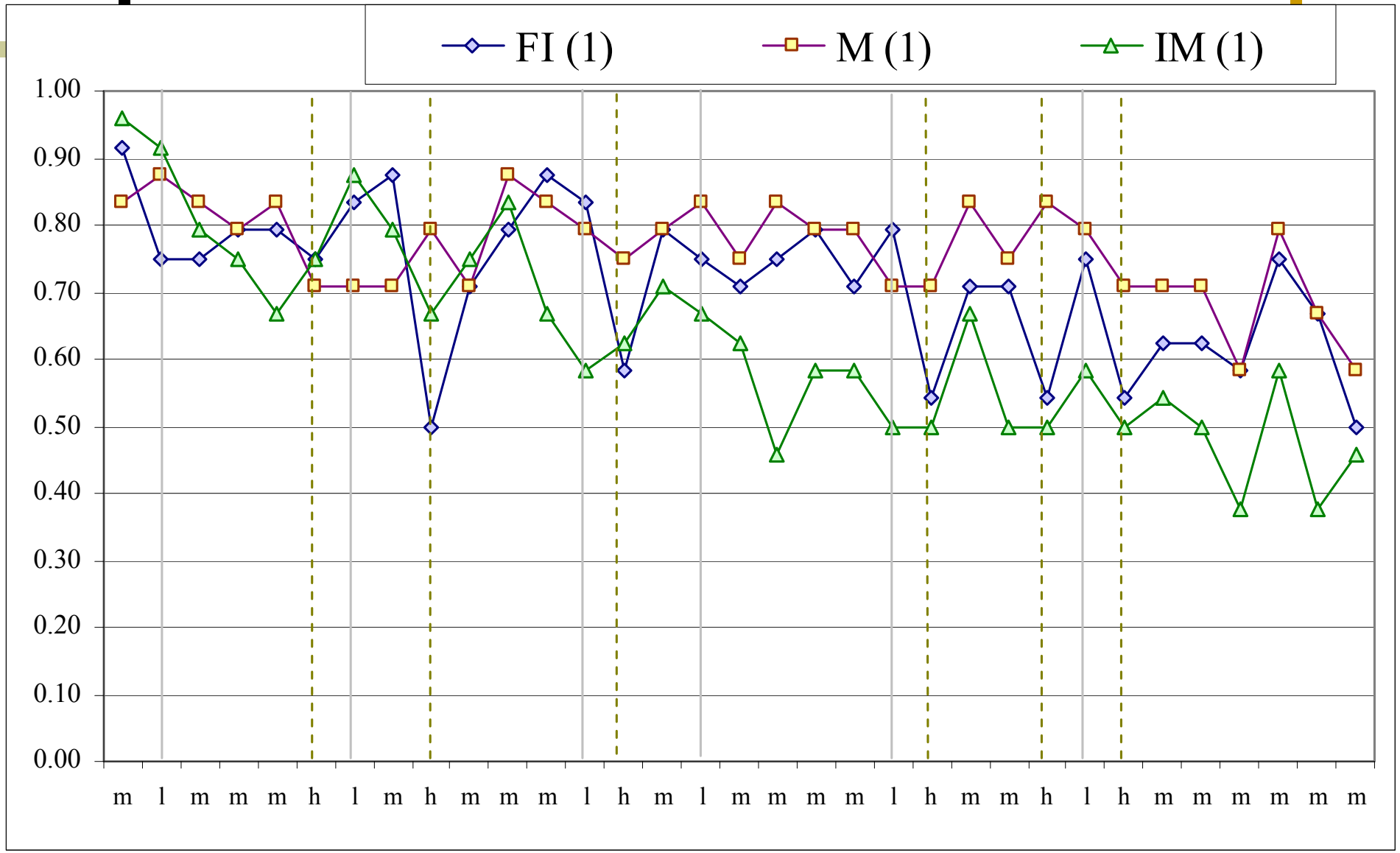
		Other Player's Choice is "B"
Your Choice was "B"		12.50 , 12.50

	Other Player's Choice is "A"	
Your Choice was "B"	12.50 , 2.10	

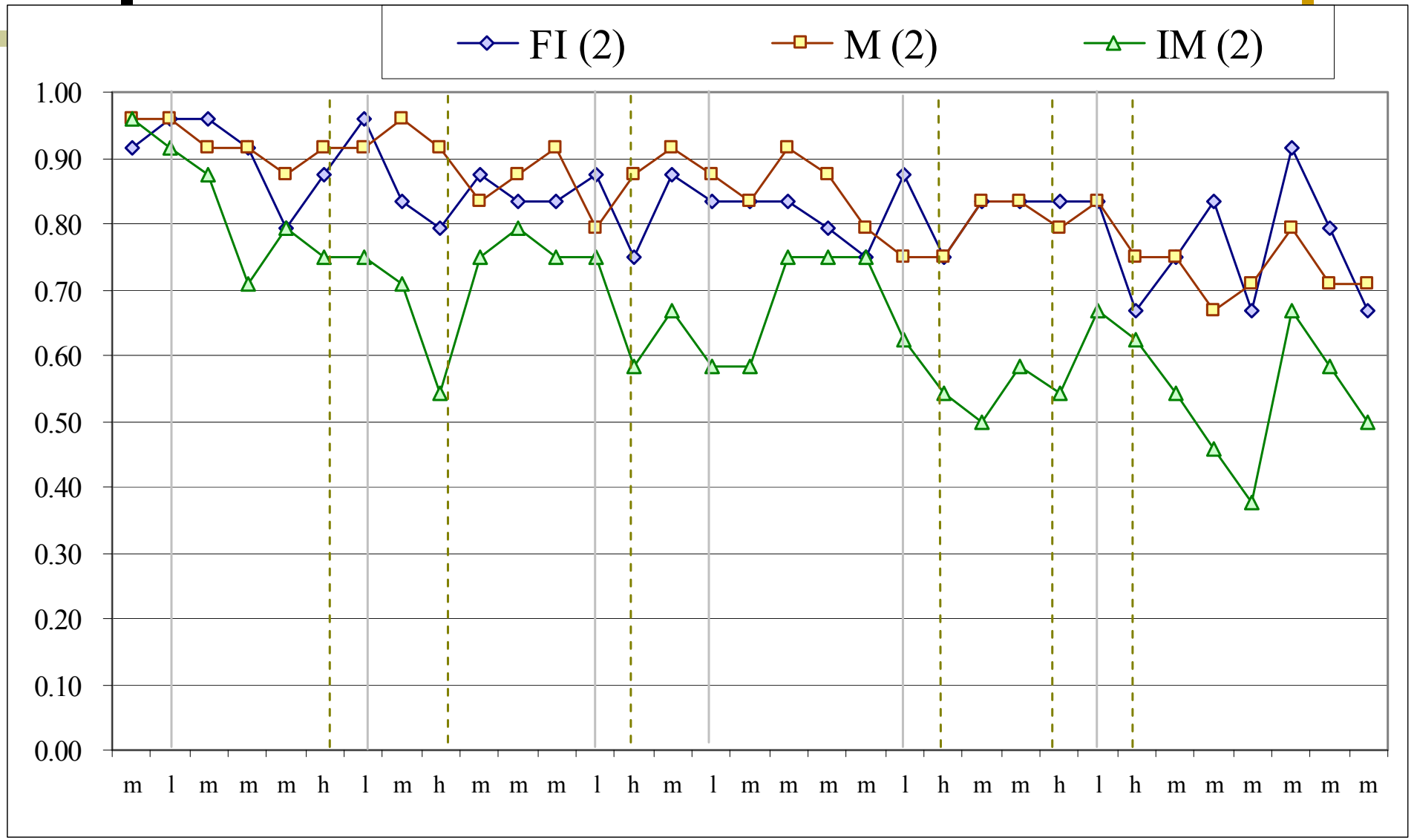
Experimental Design

- 464 subjects, 15,000 + obs
- Extensive training: instructions, practice questions, quiz, messages
- Several parameterizations (P1, P2, P3):
  - RS:
    - Incentive to collude in *medium* and *low* demand (P1)
    - Incentive to collude in *all* demand states (P2)
  - GP: not feasible (P1); punishment length, N*=3, periods (P2)
- Robustness checks: control for risk aversion (P3), different demand draws (P2b)

Results (Parameterization 1)



Results (Parameterization 2)



Results: Information and Monitoring

Treatment	Parameterization	Frequency of Cooperation*	Frequency of Collusion**
Full Information	1	0.72 (0.45)	0.51 (0.50)
	2	*0.83 (0.38)*	*0.71 (0.46)*
Monitoring	1	0.76 (0.42)	0.59 (0.49)
	2	*0.84 (0.37)*	*0.71 (0.46)*
Imperfect Monitoring	1	0.63 (0.48)	0.31 (0.46)
	2	*0.66 (0.47)*	*0.41 (0.49)*

*Either player chooses *L*. ** *Both* players chose *L*.

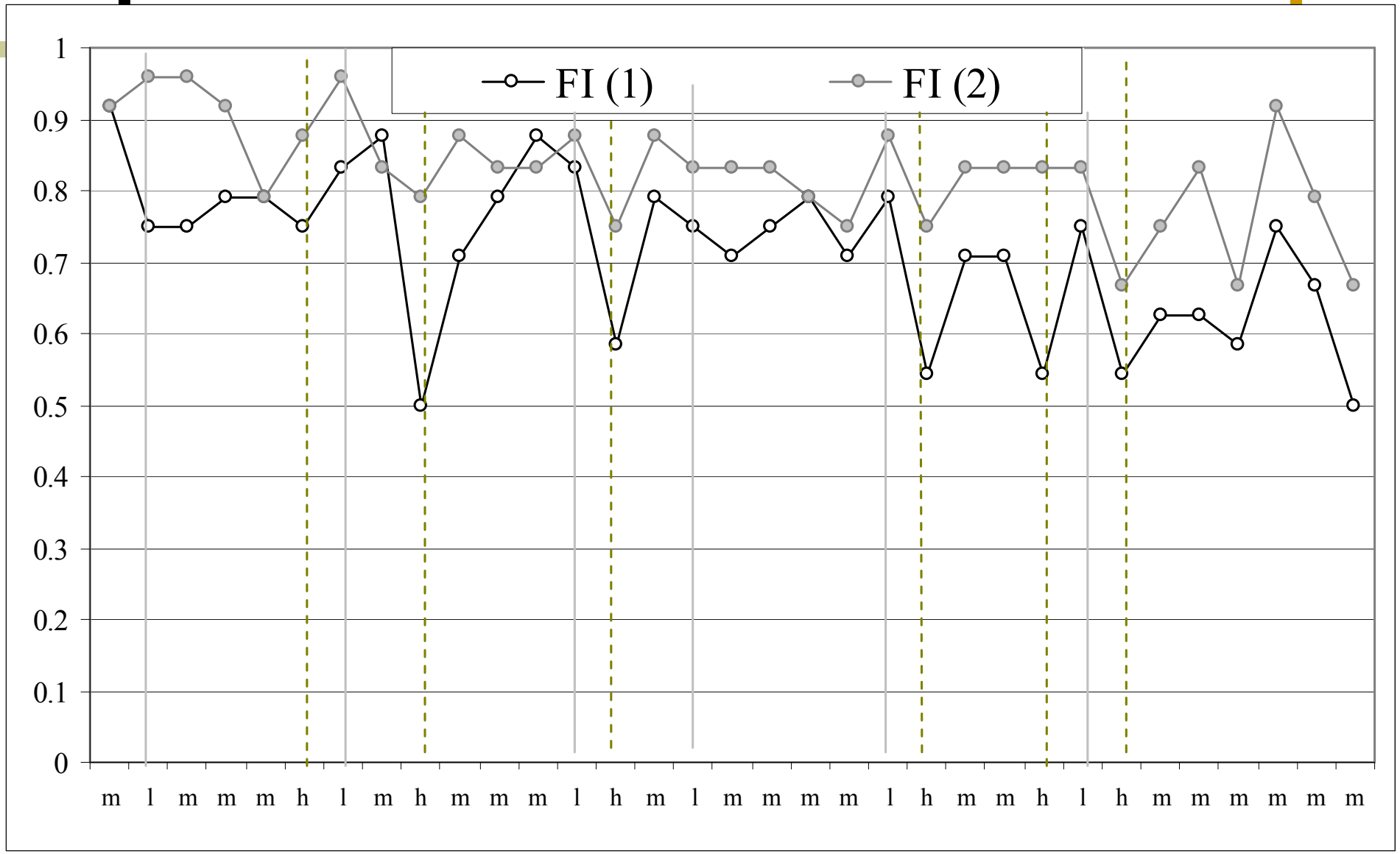
Results: Information and Monitoring

- Frequencies are different across all treatments in both parameterizations:
  - Information does not improve collusion, it can even hamper it
    - This is due to the theoretical incentives

$$E(P_s^D - P_s^{NE}) < \frac{d}{1-d}[E(P_s^C - P_s^{NE})]$$

  - Monitoring always increases collusion
  - This is confirmed in robustness checks treatments

Results FI Treatment (RS theory)



Results: RS (FI treatment)

Demand State	P	Freq. Coop.*	Freq. Collusion**
High (*h*)	1	0.58 (0.49)	0.43 (0.50)
	2	*0.80 (0.40)*	*0.67 (0.47)*
Medium (*m*)	1	0.78 (0.42)	0.56 (0.50)
	2	*0.85 (0.36)*	*0.73 (0.44)*
Low (*l*)	1	0.79 (0.41)	0.59 (0.49)
	2	*0.90 (0.30)*	*0.77 (0.42)*

Results: RS (FI treatment)

- Does RS strategy explain data better than other strategies?
  - Random strategy
  - “Tit-for-Tat” strategy
  - Finite punishment strategies (after defection)
  - Grim strategy (after defection)

1. Indicator variable determines the “theoretical” state (coop=1 or dev=0) for each strategy (an “automaton”)
2. Probit model of actual choice (coop=1, dev=0) on “theoretical” state
3. Likelihood-ratio tests wrt random strategy

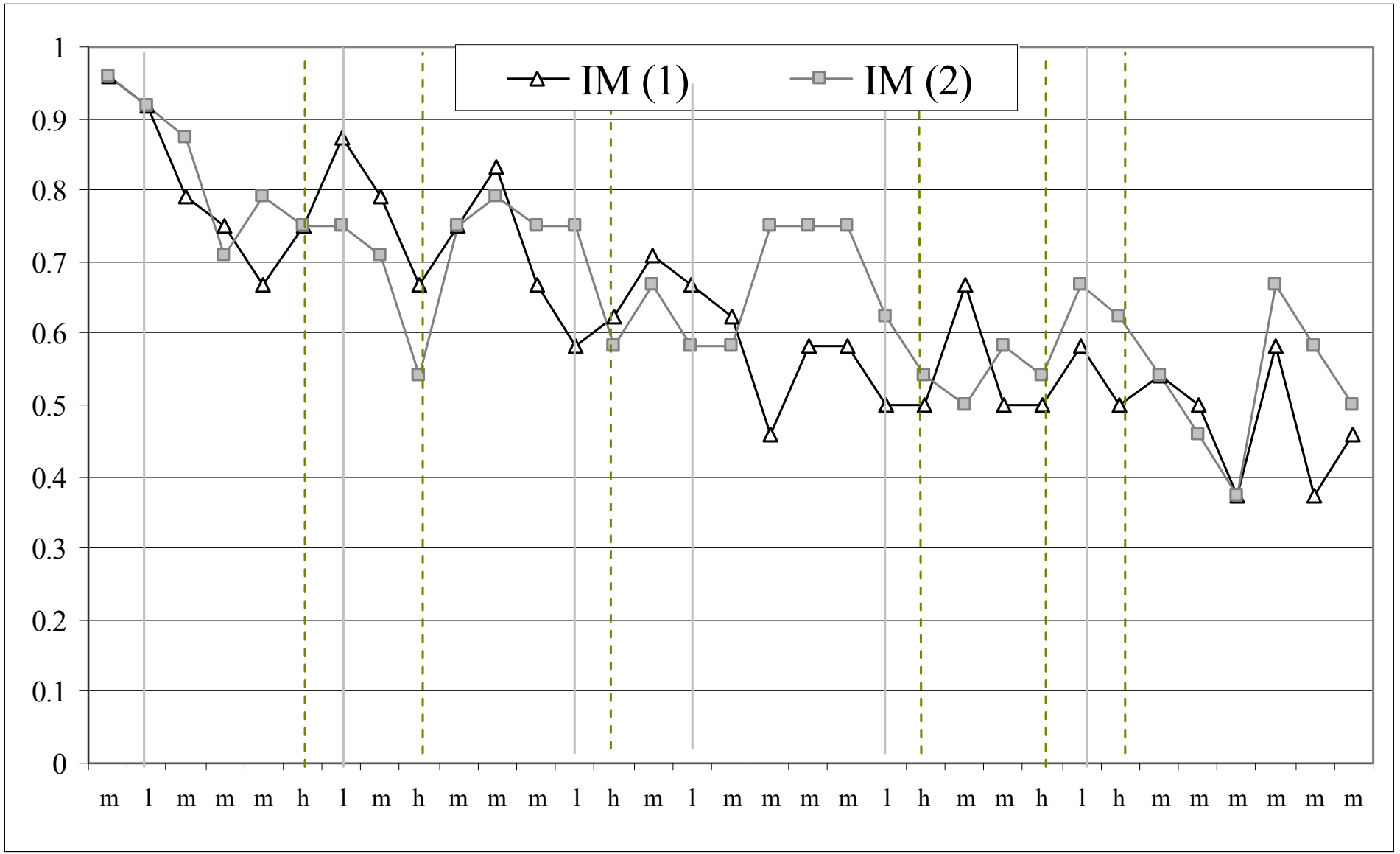
Results: RS (FI treatment), P1

Parameter	Random	RS	tt	P-2	P-3	P-6	P-∞
α	-0.80***	-0.66	-0.97*	-0.93**	-0.85**	-0.86**	-0.69*
	(0.43)	(0.46)	(0.36)	(0.39)	(0.39)	(0.35)	(0.16)
γ_1		0.92*					
		(0.14)					
γ_2			0.56*				
			(0.12)				
γ_3				0.37*	0.23**	0.53*	2.39*
				(0.11)	(0.12)	(0.14)	(0.24)
ψ	2.40*	2.56*	2.03*	2.20*	2.20*	1.98*	0.69*
	(0.52)	(0.53)	(0.43)	(0.46)	(0.45)	(0.41)	(0.23)
r	0.69*	0.72*	0.60*	0.65*	0.65*	0.59*	0.69*
LL	-450.84	-427.84	-440.41	-445.30	-449.17	-444.16	-422.07
LR Test	N/A	46.00	20.85	11.08	3.34	13.35	57.53
(p-value)†		(<0.01)	(<0.01)	(<0.01)	(0.07)	(<0.01)	(<0.01)

Results: RS (FI treatment)

- Strategies implied by RS equilibrium seem supported by data
- Grim strategy appears to explain data best
  - Important: grim strategy is assumed by RS to derive their predictions
- These are tests on *individual* choices
- Test on *outcomes:*
  - Parm. 1: ***54% (RS)***, 51% (always collude), 29% (always defect), 21% (H,L or L,H)
  - Parm. 2: ***71% (always collude)***, 65% (RS), 17% (always defect), 12% (H,L or L,H)

Results IM Treatment (GP theory)



Results: GP (IM treatment)

- Cooperation is lower during price war periods predicted by GP (especially for infinite price wars)
- How does GP do against other individual (complex) strategies?
- Random strategy, and “threshold” strategies based on noisy signal (price)
  1. One threshold:
     - Deviation triggered by low price; reversion to collusion after fixed periods or never (grim strategy)
  2. Two thresholds:
     - Deviation triggered by a low price; reversion to collusion after a high price

Results: GP (IM treatment), P2

	Random	GP_N		One-Threshold, N=punishment period			Two-Thresholds	
				$k = p_1$		$k = p_2$	$k^{down} = p_1$ $k^{up} = p_3$	$k^{down} = p_1$ $k^{up} = p_4$
		N=3	N=∞	N=8	N=∞	N=∞		
γ	N/A	0.33*	1.30*	0.74*	1.33*	1.45*	1.25*	1.33*
LL	-549.8	-543.6	-523.7	-526.2	-502.3	-523.6	-503.9	-502.3
LR†	N/A	12.50	52.25	47.22	95.02	52.42	91.78	95.02
p-value		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Results: GP (IM treatment)

- Random strategy can be rejected in favor of GP equilibrium
- Grim strategy appears to explain data best
- There are trigger strategies, but different than predicted by GP
  - Longer duration, or duration determined by signal
  - Not necessarily triggered by the predicted signals
- Test on *outcomes:*
  - Parm. 1: 72% ***(GP∞)***, 50% (GP3), 37% (always defect)
  - Parm. 2: 62% ***(GP∞)***, 51% (GP3), 33.6% (always defect)

Conclusion

- Monitoring appears to matter the most in this setting
- Less information may increase collusion
- Data support RS and GP predictions, but infinite price wars appear more likely
- Experiments can help us sort out the likely predictions from the unlikely ones
- Merger guidelines: factors affecting collusion
- Observed data vs. theoretical predictions

Robustness and Caveats

- Risk aversion
  - Controlled for
- Students as subjects
  - Dyer, Kagel, Levin, 1989; Potters van Winden, 2000; Davis and Holt, 1993; Ball and Cech, 1996
- Infinitely repeated game

Parameterization 1

High Demand (*h*), probability: 0.20

		Player 2	
		L	H
Player 1	L	26.00, 26.00	7.50, 43.00
	H	43.00, 7.50	12.50, 12.50

Medium Demand (*m*), probability: 0.60

		Player 2	
		L	H
Player 1	L	7.50, 7.50	2.10, 12.50
	H	12.50, 2.10	3.50, 3.50

Low Demand (*l*): 0.20

		Player 2	
		L	H
Player 1	L	2.10, 2.10	0.60, 3.50
	H	3.50, 0.60	1.00, 1.00

Parameterization 2

High Demand (*h*), probability: 0.20

		Player 2	
		L	H
Player 1	L	31.00, 31.00	9.00, 43.00
	H	43.00, 9.00	12.50, 12.50

Medium Demand (*m*), probability: 0.60

		Player 2	
		L	H
Player 1	L	9.00, 9.00	2.50, 12.50
	H	12.50, 2.50	3.50, 3.50

Low Demand (*l*): 0.20

		Player 2	
		L	H
Player 1	L	2.50, 2.50	0.70, 3.50
	H	3.50, 0.70	1.00, 1.00

Imperfect Public Monitoring

		High Demand	
		Player 2	
		L	*H*
Player 1	***L***	p_4	p_3
	H	P_3	p_2

		Medium Demand	
		Player 2	
		L	*H*
Player 1	***L***	p_3	p_2
	H	p_2	p_1

		High Demand	
		Player 2	
		L	*H*
Player 1	***L***	p_2	p_1
	H	p_1	p_0