Calibration, Forecast-Hedging, and Nash Dynamics

Sergiu Hart

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Nash 75 @ Oxford

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Joint work with

Dean P. Foster

University of Pennsylvania &

Amazon Research NY

Papers

Papers

- Sergiu Hart
  “Calibration: The Minimax Proof”, 1995 [2021]
  www.ma.huji.ac.il/hart/publ.html#calib-minmax

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- Sergiu Hart
  “Calibration: The Minimax Proof”, 1995 [2021]
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- Dean P. Foster and Sergiu Hart
  “Smooth Calibration, Leaky Forecasts, Finite Recall, and Nash Dynamics”
  Games and Economic Behavior 2018
  www.ma.huji.ac.il/hart/publ.html#calib-eq

Papers

Papers

- Dean P. Foster and Sergiu Hart
  "Forecast Hedging and Calibration"
  Journal of Political Economy 2021
  www.ma.huji.ac.il/hart/publ.html#calib-int

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- Dean P. Foster and Sergiu Hart
  " 'Calibeating': Beating Forecasters at Their Own Game"
  Theoretical Economics 2023
  www.ma.huji.ac.il/hart/publ.html#calib-beat

Calibration

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    (or: is close to p in the long run)

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CALIBRATION ***can be guaranteed***

(no matter what the weather will be)

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* **NON-Bayesian, NO statistical assumptions !**

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- Foster and Hart 2016 [publ 2021]: simplest procedure, by "Forecast Hedging"

Forecast-Hedging

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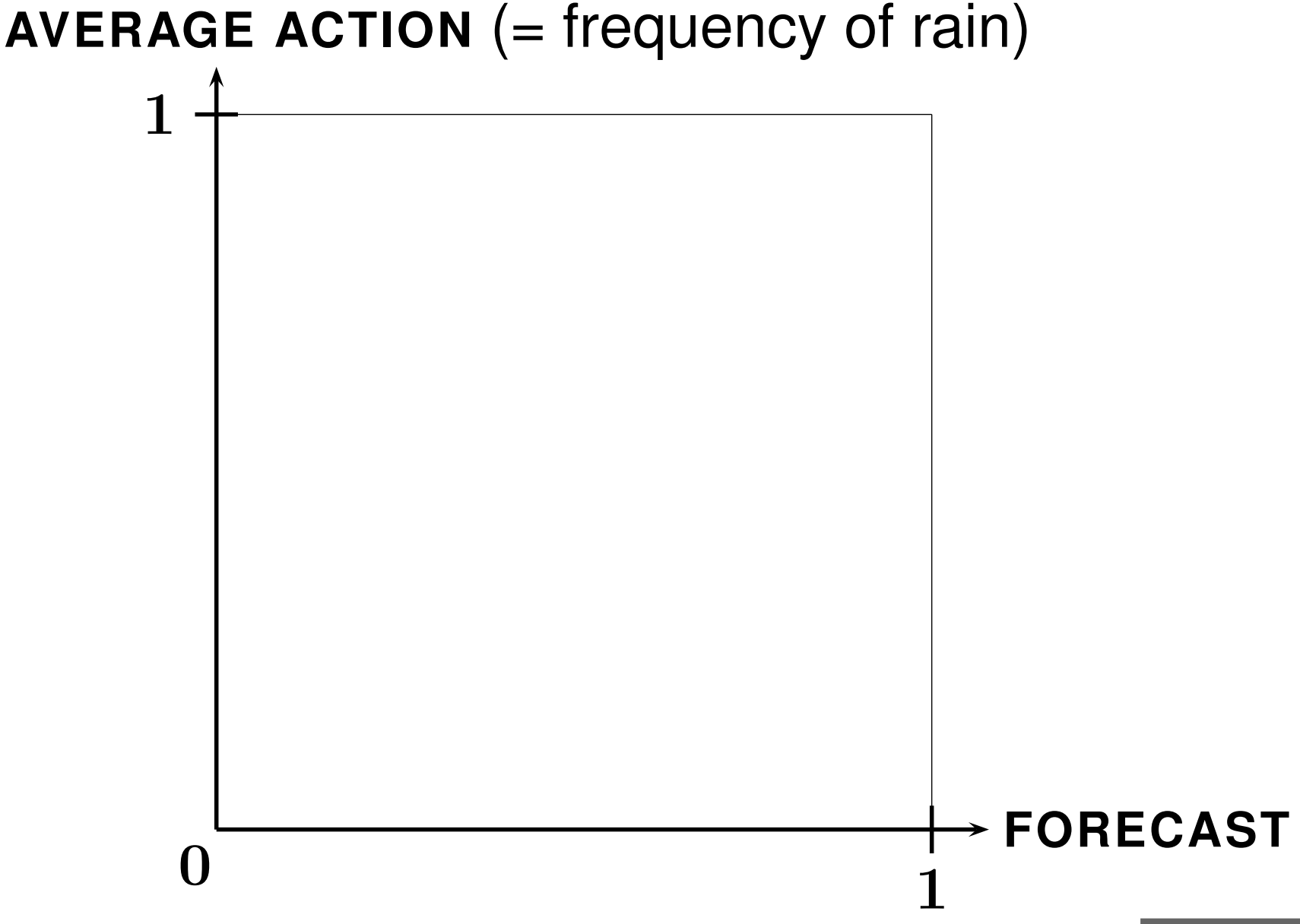

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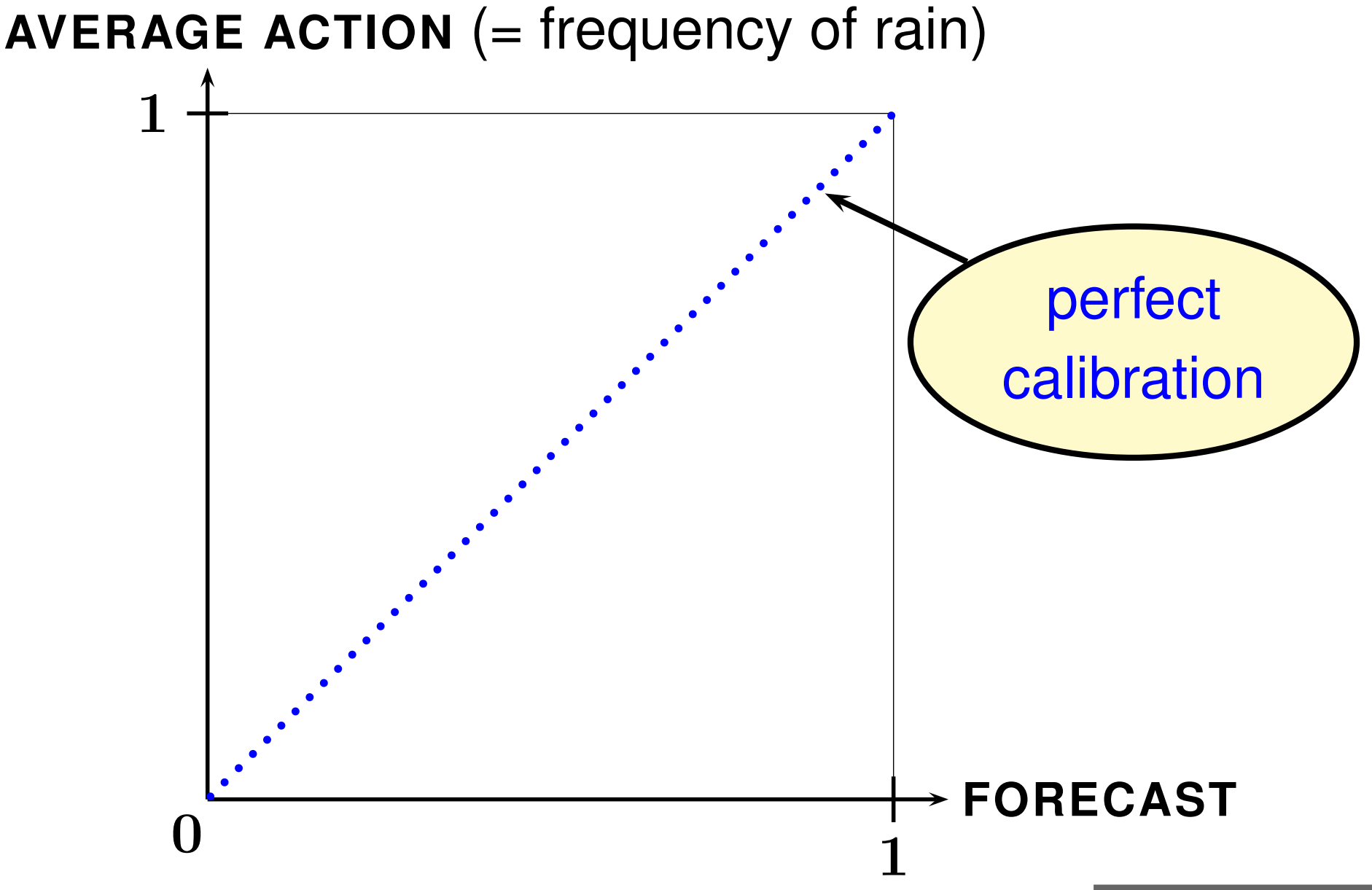

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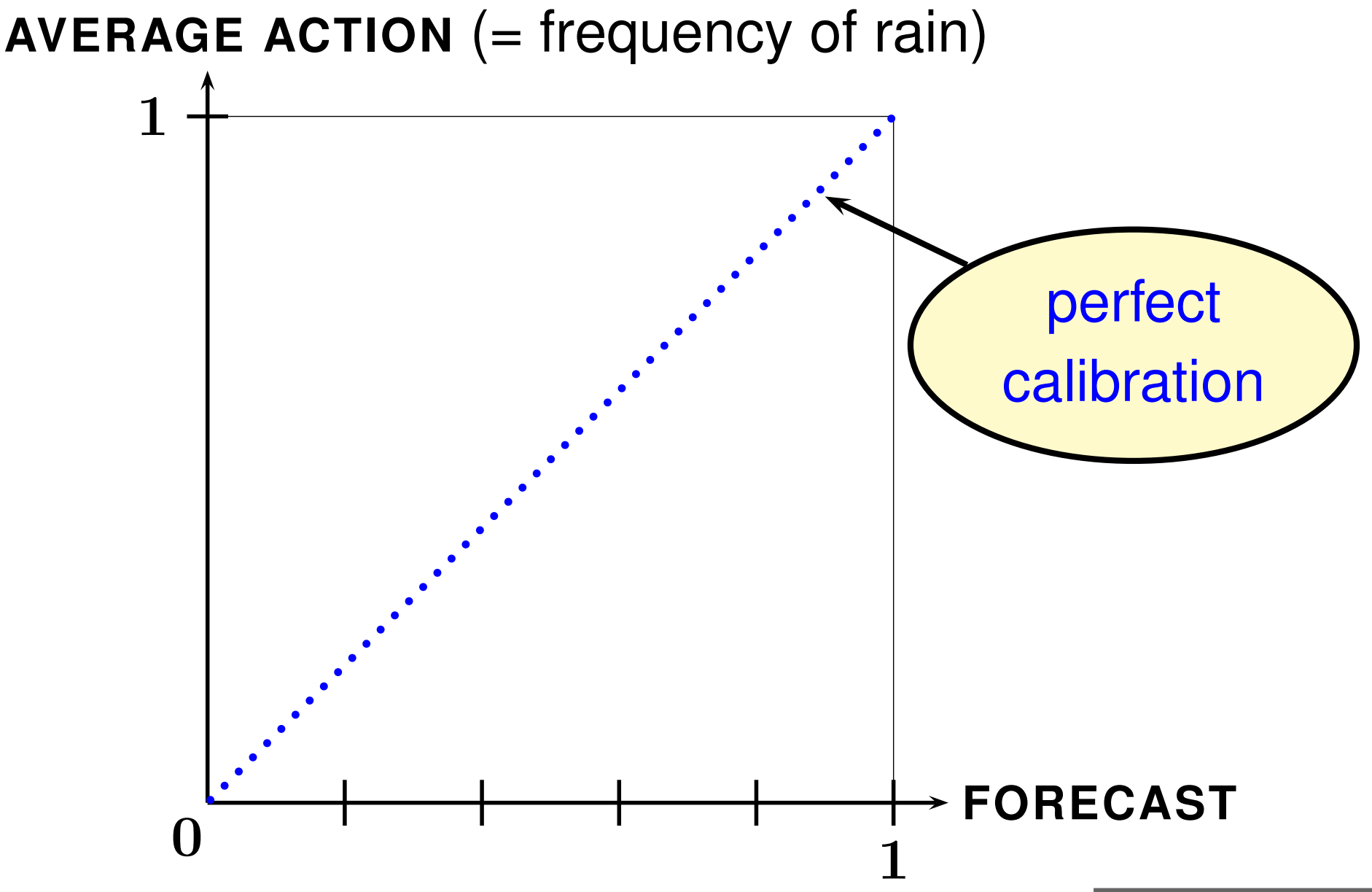

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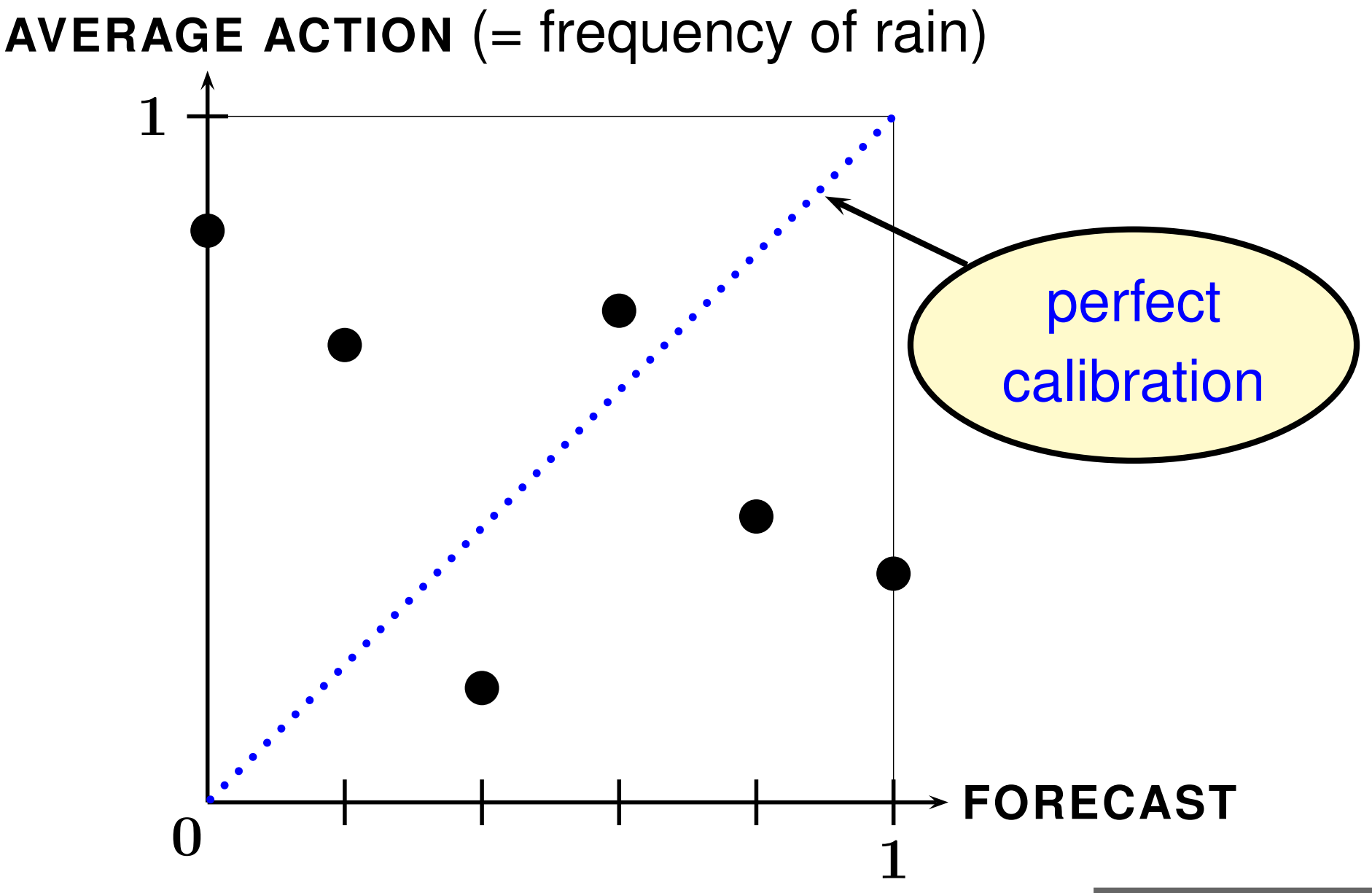

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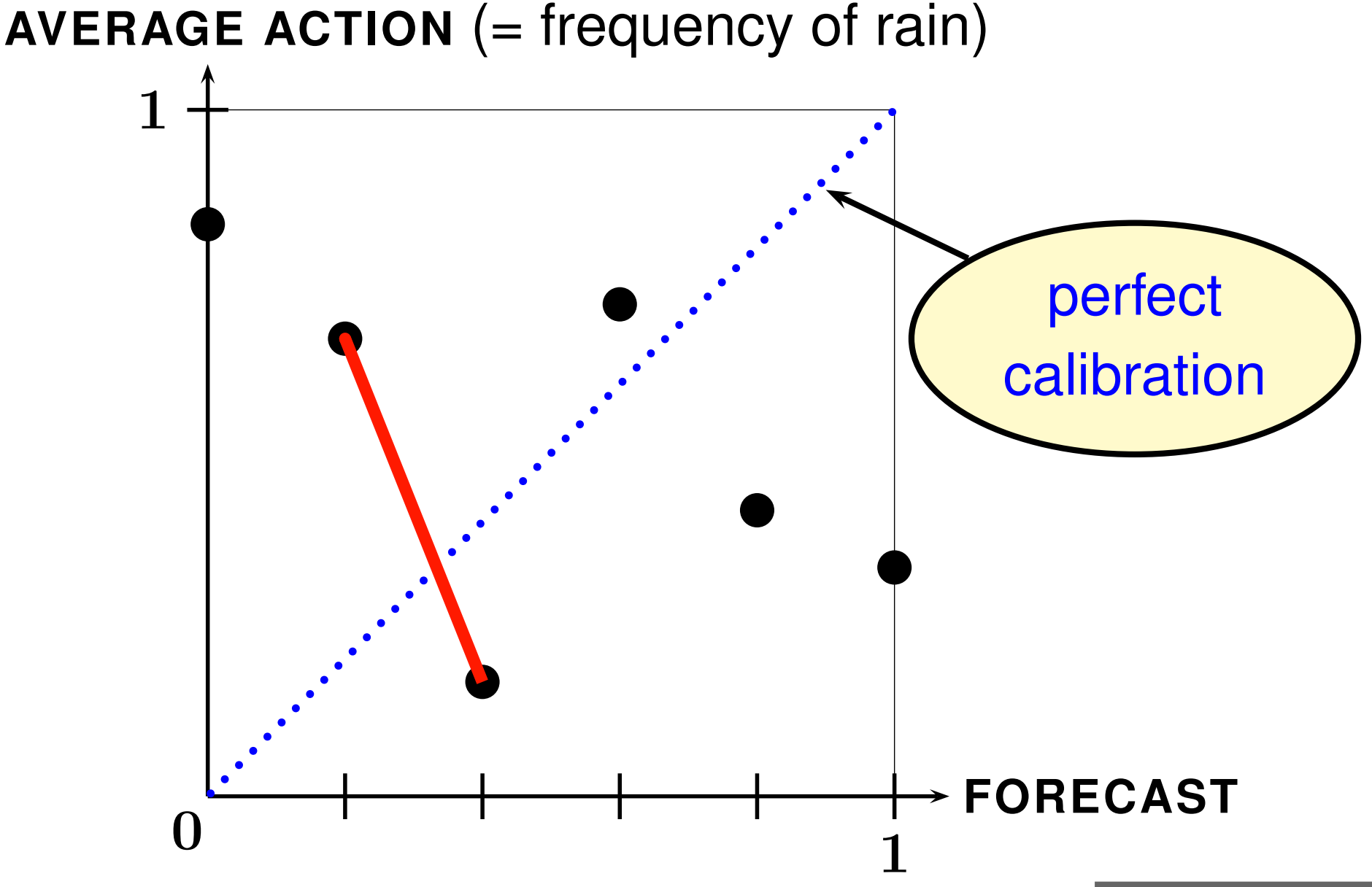

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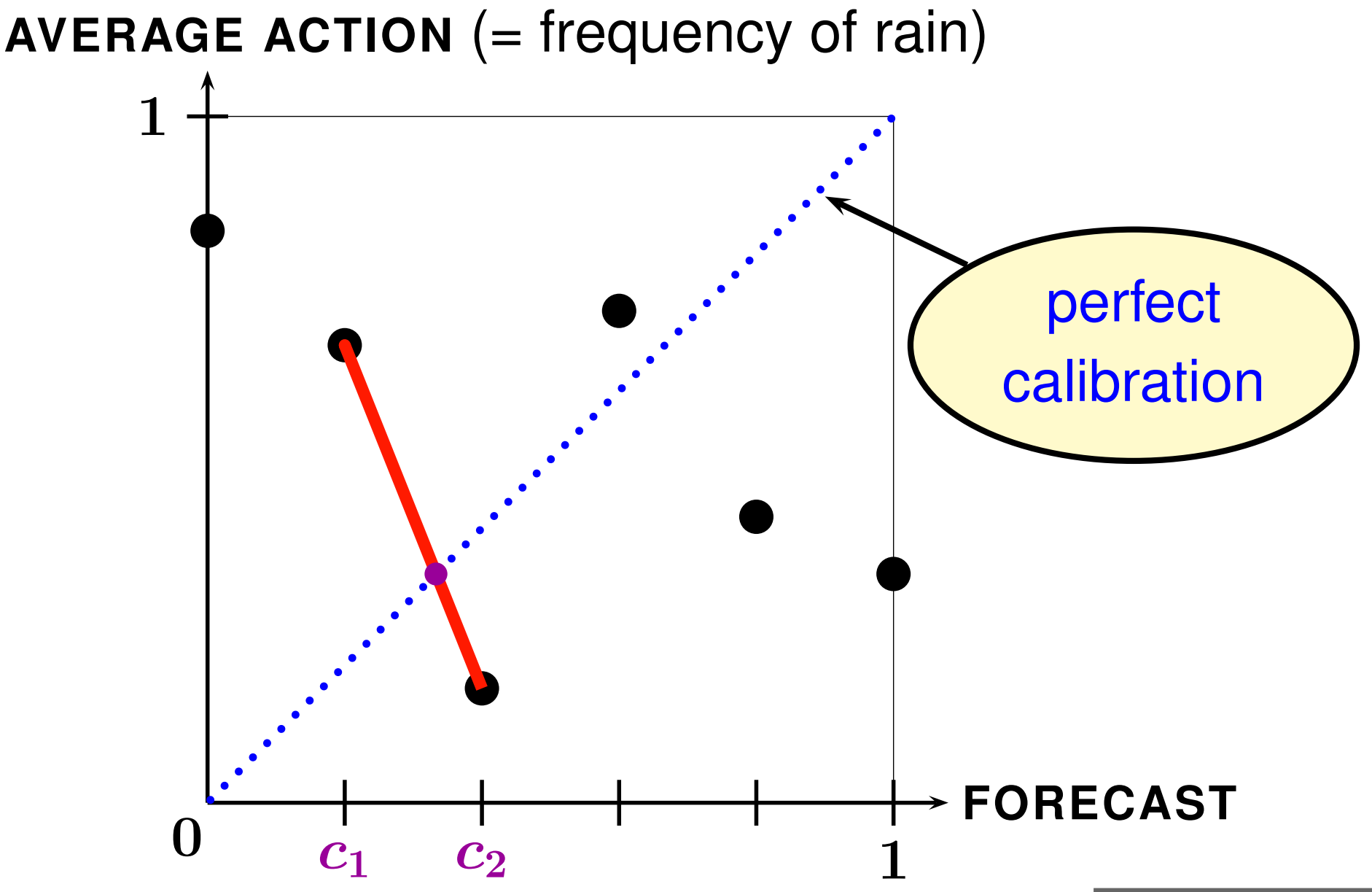

Calibration in Practice

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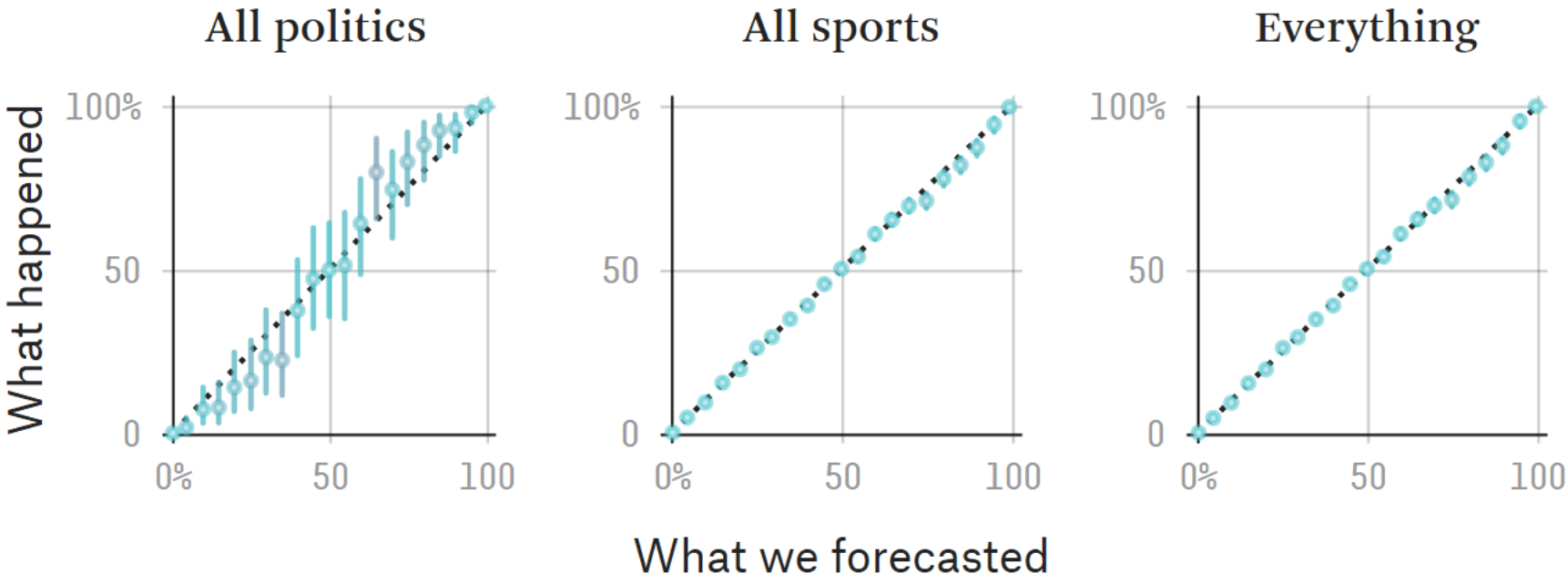
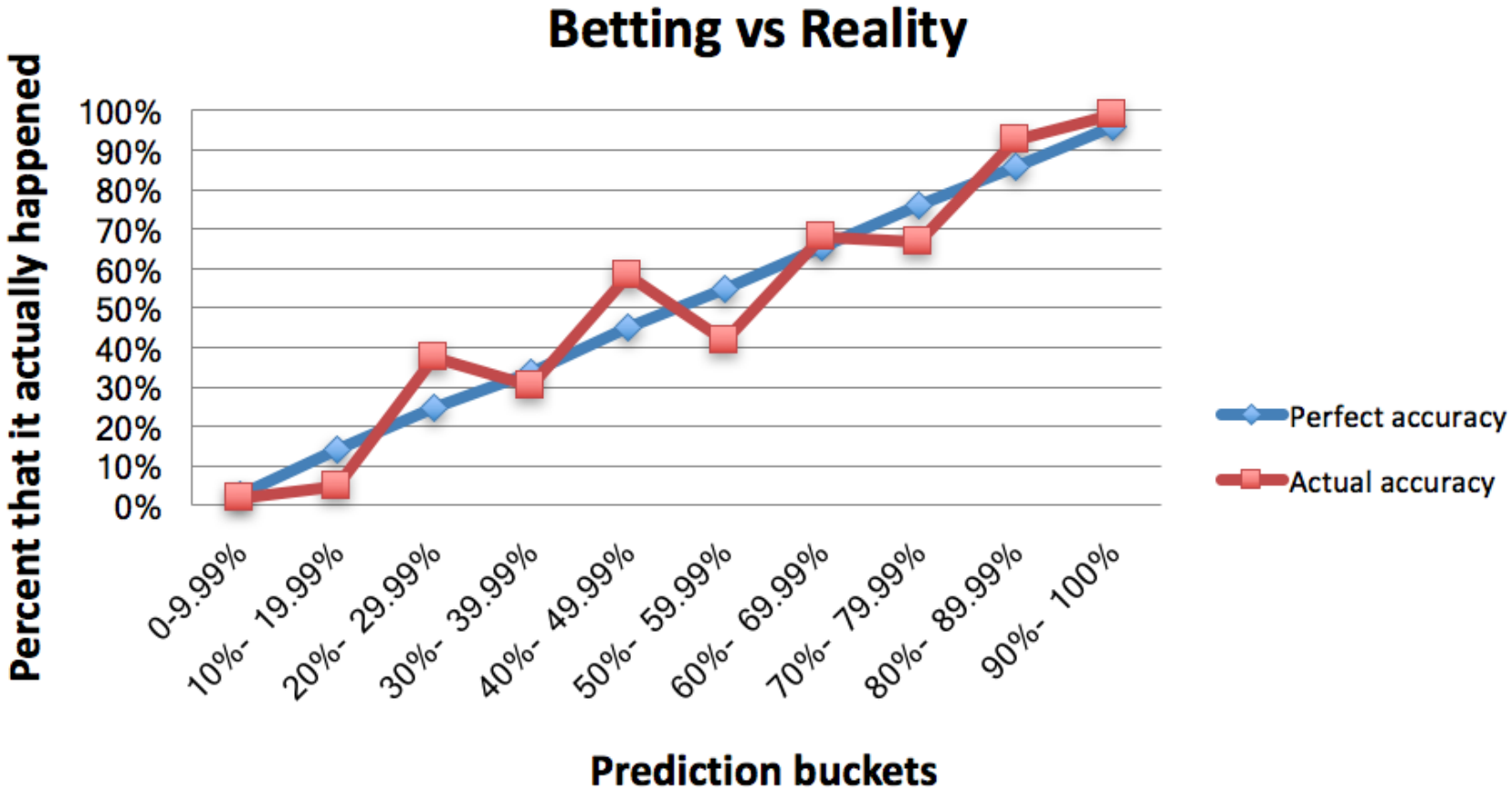


Calibration plots of FiveThirtyEight.com
(as of June 2019)

Calibration in Practice



Calibration plot of ElectionBettingOdds.com (2016 – 2018)

No Calibration

No Calibration

- **CALIBRATION** ***cannot*** be guaranteed when:

No Calibration

- **CALIBRATION** ***cannot*** be guaranteed when:
  - Forecast is known before the rain/no-rain decision is made
    (**"LEAKY FORECASTS"**)

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  - Forecaster uses a ***deterministic*** forecasting procedure

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Oakes 1985

Continuous Calibration

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- **CONTINUOUS CALIBRATION**: combine the days when the forecast was ***close to*** p (smooth out the calibration score)

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- **Theorem**:

> There exists a ***deterministic*** procedure that is **CONTINUOUSLY CALIBRATED**.

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Foster and Kakade (2004, 2006)
Foster and Hart (2018, **2021**)

Forecast-Hedging: Calibration

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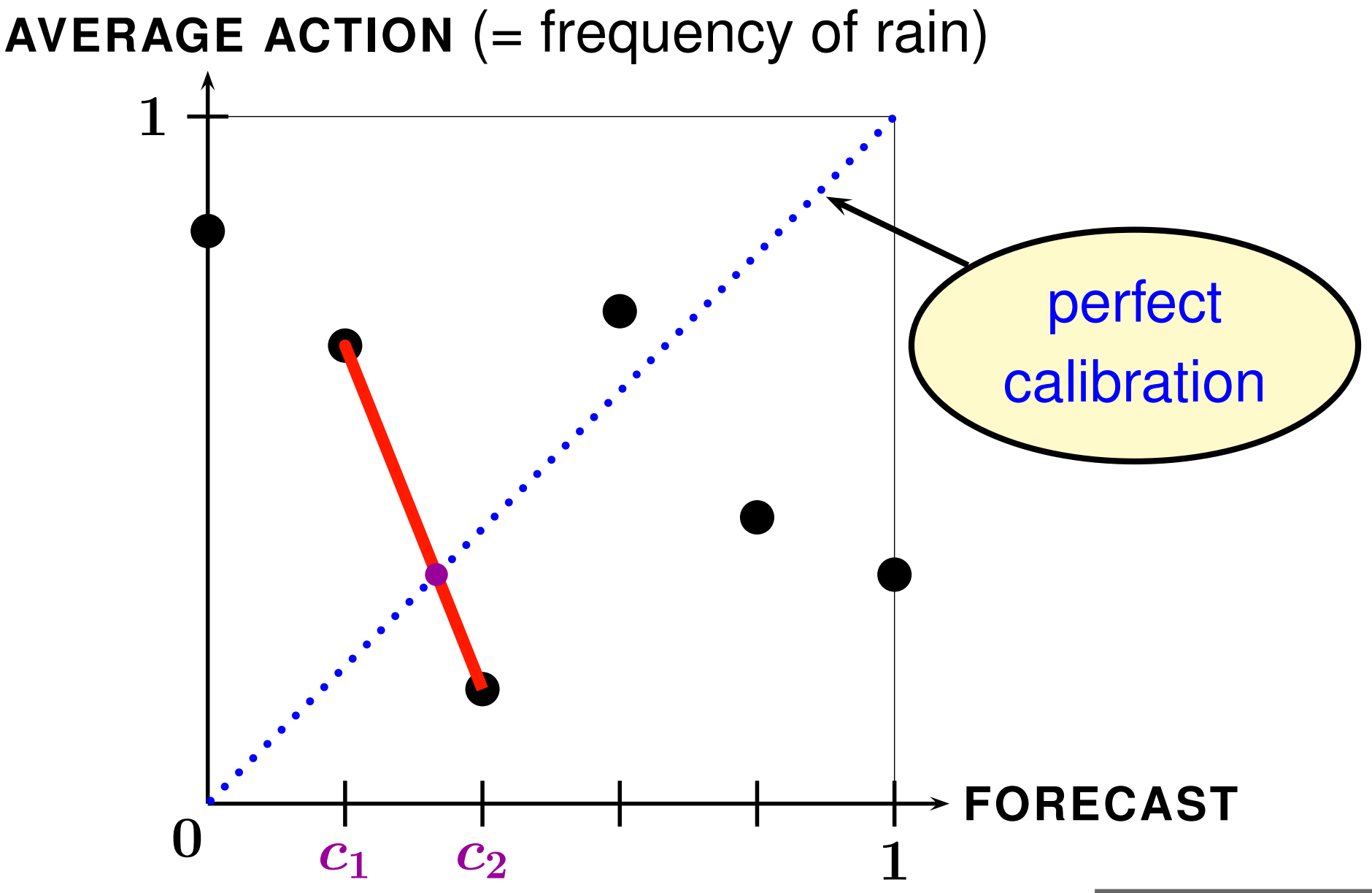
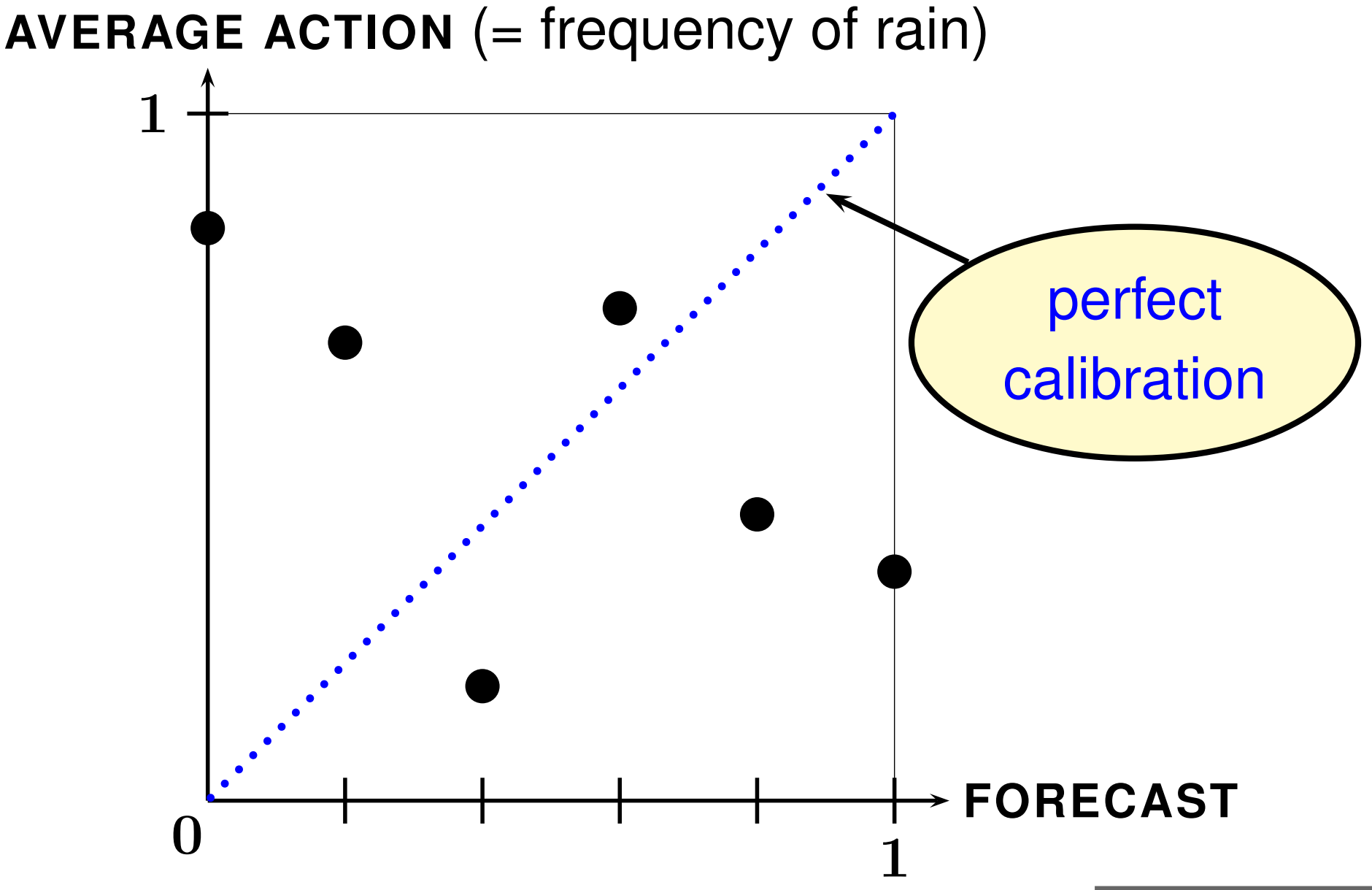
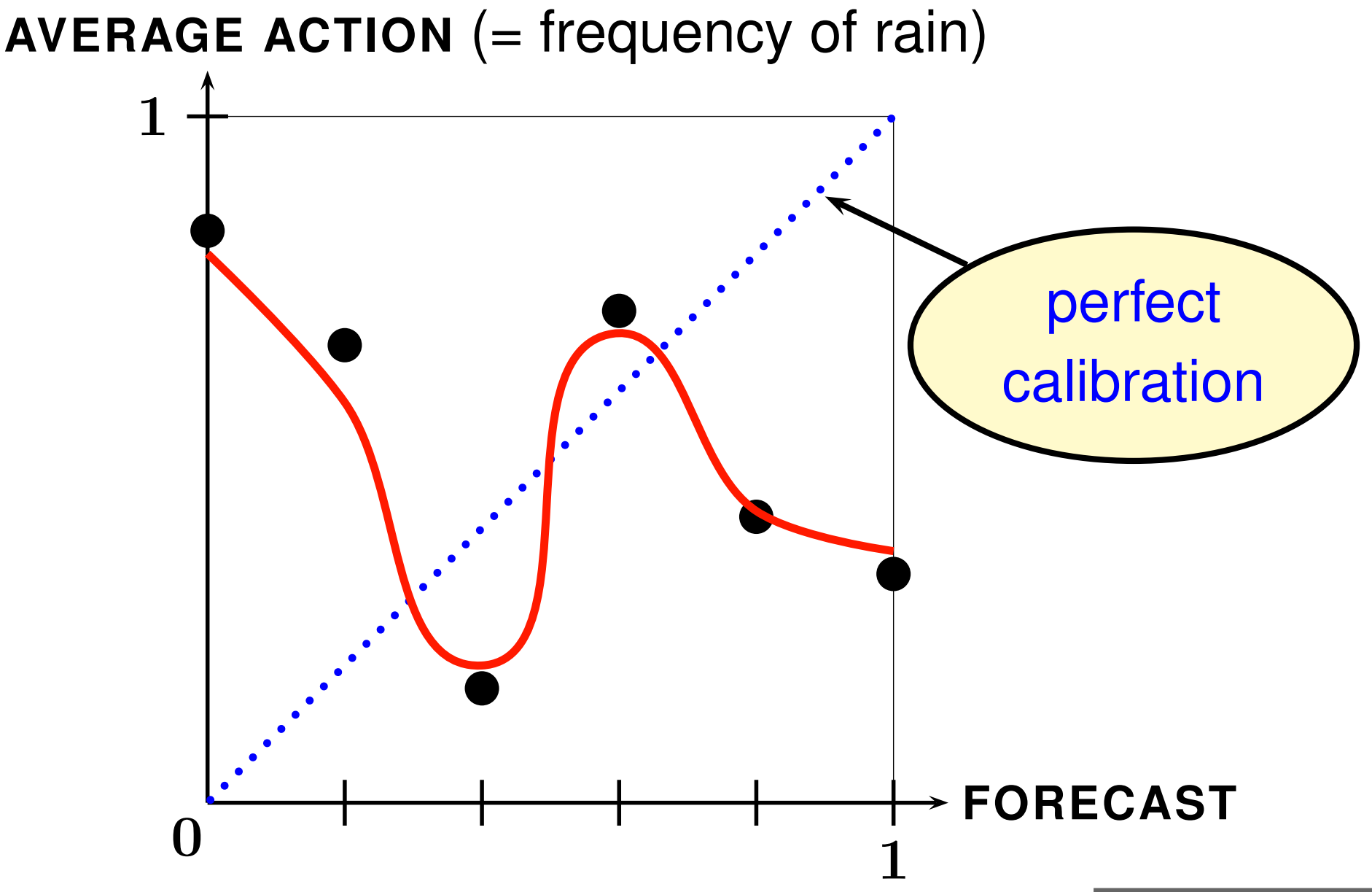


Forecast-Hedging:



Forecast-Hedging: Continuous Calibra



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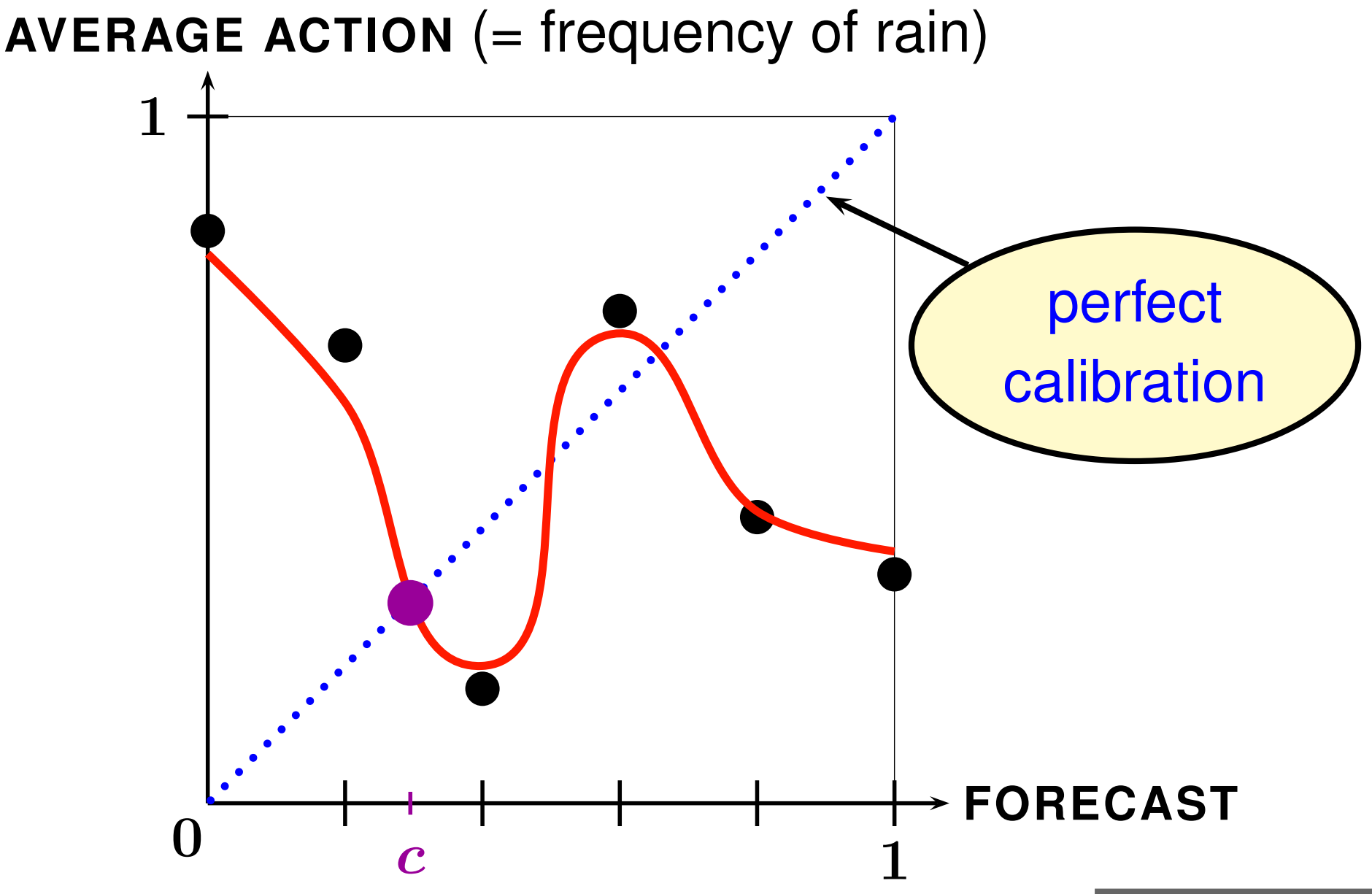

Forecast-Hedging

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In general (for dimension ≥ 2):

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In general (for dimension ≥ 2):

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Forecast-Hedging

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- forecasting ?

Forecast-Hedging

- fore-casting ?

Forecast-Hedging

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- **BACK-CASTING !**

Forecast-Hedging

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  ("Politician's Lemma")

Continuous Calibration: Implications

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- For ***forecasting***:

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  - nothing much ... (easier to pass the test)

Continuous Calibration: Implications

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- For ***game dynamics***:

Continuous Calibration: Implications

- For ***forecasting***:
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- For ***game dynamics***:
  - Nash dynamics

Game Dynamics

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General n-person game

Game Dynamics

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- Players ***forecast*** the play in the next period

Game Dynamics

General n-person game

- Players ***forecast*** the play in the next period
- Players choose their actions in ***response*** to the forecasts

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- Players ***forecast*** the play in the next period
  - ***calibrated forecasts***
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$\Rightarrow$ **Long-run play ?**

Calibrated Learning

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(= empirical distribution of play)
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Foster and Vohra 1997

Continuously Calibrated Learning

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- A ***deterministic continuously calibrated forecast*** on the play of all players in the next period

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$\Rightarrow$ **$1-\varepsilon$ OF THE TIME**
the play is a **NASH ε-EQUILIBRIUM**
in the long run (a.s.)

Continuously Calibrated Learning

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(F) A ***continuously calibrated deterministic*** procedure, which gives in each period t a "forecast" of play c_t in $\Pi_{i \in N} \Delta(A^i)$

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In each period t, each player i:

1. runs the procedure **(F)** to get c_t
2. plays $g^i(c_t)$ given by **(P)**

Continuously Calibrated Learning

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CONTINUOUSLY CALIBRATED LEARNING:

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- is a stochastic ***uncoupled*** dynamic

Continuously Calibrated Learning

CONTINUOUSLY CALIBRATED LEARNING:

- is a stochastic ***uncoupled*** dynamic
  - ***Nash ε-equilibria are played at least $1-\varepsilon$ of the time***

in the long run (a.s.)

Continuously Calibrated Learning

Proof:

Continuously Calibrated Learning

Proof:

$$\textbf{play}_t = g(c_t)$$

Continuously Calibrated Learning

Proof:

- ***continuous calibration***
  $\Rightarrow$ $\textbf{play}_t = g(c_t) \approx c_t$

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  - $g(\textbf{play}_t) = g(g(c_t)) \approx g(c_t) = \textbf{play}_t$

Why Continuous ?

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- **CONTINUOUS BEST REPLY**

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- **CONTINUOUS BEST REPLY**

  $\Rightarrow$ fixed point = **NASH EQUILIBRIUM**

Dynamics and Equilibrium

Dynamics and Equilibrium

"LAW OF CONSERVATION OF COORDINATION":

Dynamics and Equilibrium

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There must be some COORDINATION —

Dynamics and Equilibrium

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Dynamics and Equilibrium

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Dynamics and Equilibrium

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(Hart and Mas-Colell 2003)

Calibration, Dynamics, Equilibria

Calibration, Dynamics, Equilibria

MINIMAX universe

Calibration, Dynamics, Equilibria

MINIMAX universe

FIXEDPOINT universe

Calibration, Dynamics, Equilibria

MINIMAX universe

- ***stochastic***
  forecast-hedging

FIXEDPOINT universe

Calibration, Dynamics, Equilibria

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Calibration, Dynamics, Equilibria

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Calibration, Dynamics, Equilibria

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Calibration, Dynamics, Equilibria

MINIMAX universe

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- ***MM***-procedures
- ***classic***
  calibration

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Calibration, Dynamics, Equilibria

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FIXEDPOINT universe

- ***deterministic***
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- ***FP***-procedures
- ***continuous***
  calibration

Calibration, Dynamics, Equilibria

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- ***correlated*** equilibria

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Calibration, Dynamics, Equilibria

MINIMAX universe

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  calibration
- ***correlated*** equilibria
- ***time-average***

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- ***classic***
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- ***time-average***

FIXEDPOINT universe

- ***deterministic***
  forecast-hedging
- ***FP***-procedures
- ***continuous***
  calibration
- ***Nash*** equilibria
- ***period-by-period***

Dynamics and Nash Equilibrium

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Conference in Honor
of John Nash's 80th Birthday
Princeton University, June 2008

Dynamics and Nash Equilibrium

FACT

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There are NO general, natural dynamics leading to Nash equilibrium

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- ***"general"*** : **in all games**

Dynamics and Nash Equilibrium

FACT

There are NO general, natural dynamics leading to Nash equilibrium

- ***"general"*** : **in all games**
  rather than: in specific classes of games

Dynamics and Nash Equilibrium

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- ***"leading to Nash equilibrium"***

Dynamics and Nash Equilibrium

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- ***"leading to Nash equilibrium"*** :
  at a Nash equilibrium (or close to it) from some time on

Dynamics and Nash Equilibrium

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- ***"natural"***

Dynamics and Nash Equilibrium

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- ***"natural"*** :

Dynamics and Nash Equilibrium

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- ***"natural"*** :
  - **adaptive** (reacting, improving)

Dynamics and Nash Equilibrium

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There are NO general, natural dynamics leading to Nash equilibrium

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  - **adaptive** (reacting, improving)
  - **simple and efficient** (computation, time)

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Hart and Mas-Colell (2003, 2006, 2013),
Hart and Mansour (2010),
Babichenko and Rubinstein (2022), ...

Continuously Calibrated Learning

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- ☑ adaptive

Continuously Calibrated Learning

- ✓ adaptive
- ✓ uncoupled

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Continuously Calibrated Learning

- ✓ **adaptive**
- ✓ **uncoupled**
- × **NOT simple** (fixedpoint at each step)
- × **NOT "leading to Nash equilibrium"** (only $1 - \varepsilon$ of the time)
- ✓ **period-by-period behavior**

John Nash

John Nash

John Nash

my photo
of John Nash

John Nash

my photo
of John Nash
taking
my photo

John Nash

my photo
of John Nash
taking
my photo
of taking
his photo

John Nash

my photo
of John Nash
taking
my photo
of taking
his photo
of taking
my photo
...

John Nash Photo Equilibrium

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of John Nash
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Brazilian Game Theory Conference
São Paulo, August 2010