Lecture 3: Innovation and Information

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Why Tesla and not GM or Toyota?

Why Amazon and not Sears or Wal-Mart?

Why are startups the source of so many innovations?

Hard disk industry

Disk size	Years	Innovating Firms
14 in	< 1978	IBM
8 in	1978	Shugart, Micropolis, Priam, Quantum, ...
5.25 in	1980	Seagate
3.5 in	1985	Rodime, (Conner)
2.5 in	1989	Prairietek, (Conner)
1.8 in	1995	*New entrants (98% share)*

Source: Christiansen (1997)

Incentives to innovate

- "Replacement effect" favors entrant (Arrow, 1962)
  - since $m - m_0 < m$
- "Preemption effect" favors incumbent (G&N, 1982)
  - since $m > 2d$
- Igami (2017): Arrow explains 60% of turnover in hard disks
- Our model—only informational asymmetry

Incentives to innovate

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  - since $m - m_0 < m$
- "Preemption effect" favors incumbent (G&N, 1982)
  - since $m - d > d$
- Igami (2017): Arrow explains 60% of turnover in hard disks
- Our model—only informational asymmetry

Patent race

- Two firms
  - Firm 1 (incumbent)
  - Firm 2 (startup)
- Continuous time, interest rate r
- R&D—flow cost c
- First success—flow profits m forever
- Irrevocable exit, observed (possibly with delay)

Uncertainty

- Unknown state
  - G success at Poisson rate λ independently
  - B no chance of success

- Prior $\Pr[\,G\,] = \pi$

Antecedents

- R&D
  - Choi (1991), Malueg and Tsutsui (1997)
  - Moscarini and Squintani (2010)
- Strategic Experimentation
  - Keller, Rady, Cripps (2005)
  - Dong (2018)
- War of Attrition
  - Chen and Ishida (2017)

Asymmetric information

- Private signals $s_i \in \{g_i, b_i\}$ at time 0:

$$\Pr[\, g_i \mid G \,] = \Pr[\, b_i \mid B \,] = q_i \geq \tfrac{1}{2}$$

- Only asymmetry is informational: $q_1 > q_2$

Main result: Disadvantageous Information

Proposition: When firm 1 is much better informed, there is a unique equilibrium in which firm 2 wins more often, and has a higher payoff, than firm 1.

Key idea

- Asymmetric information leads to asymmetric learning
- Poorly informed startup has a stronger incentive to learn and this overcomes informational disadvantage
- But is this kind of learning “real”?

Pharmaceuticals

› Data from over 10K projects that reached phase II trials

Findings:

1. Rival quitting similar project increases quitting probability
2. Technology effect stronger than competitive effect
3. Newer firms learn more from established firms than the other way around (in WP)

Source: Krieger (2019)

Pharmaceuticals

- In 2018 Incyte stopped trial of an IDO-inhibitor based cancer drug
- NewLink Genetics then quit
  - "in the context of the failure of a competitor's trial ..."
- Bristol-Myers also followed, citing
  - "emerging data on the IDO pathway."

Source: Krieger (2019)

Main result: Disadvantageous Information

Proposition: When firm 1 is much better informed, there is a unique equilibrium in which firm 2 wins more often, and has a higher payoff, than firm 1.

Upstart equilibrium

Proposition 1: There is a PBE in which firm 2 wins more often, and has a higher payoff, than firm 1.

Upstart equilibrium

Proposition 1: There is a PBE in which firm 2 wins more often, and has a higher payoff, than firm 1.

Proposition 2: When firm 1 is much better-informed, there is a unique Nash outcome.

π Single firm problem

- Define p^* by

$$p^* \lambda \times \frac{m}{r} = c$$

Success rate $\times$ gain $=$ cost

- Or

$$p^* = \frac{rc}{\lambda m}$$

Single firm problem

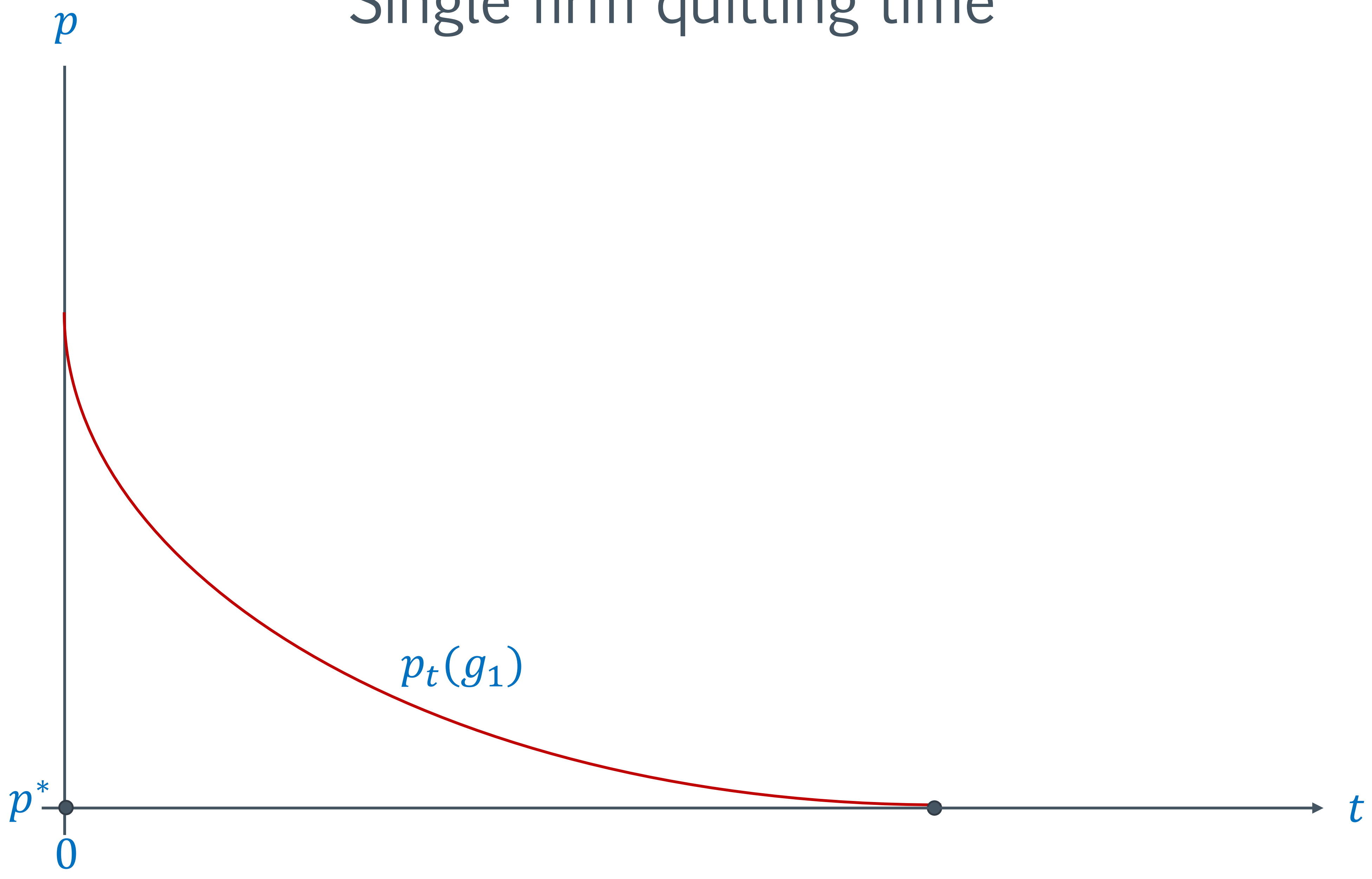
Firm i should invest as long as current belief

$$p_t(s_i) = \Pr\left[\, G \mid s_i, t \right] > p^*$$

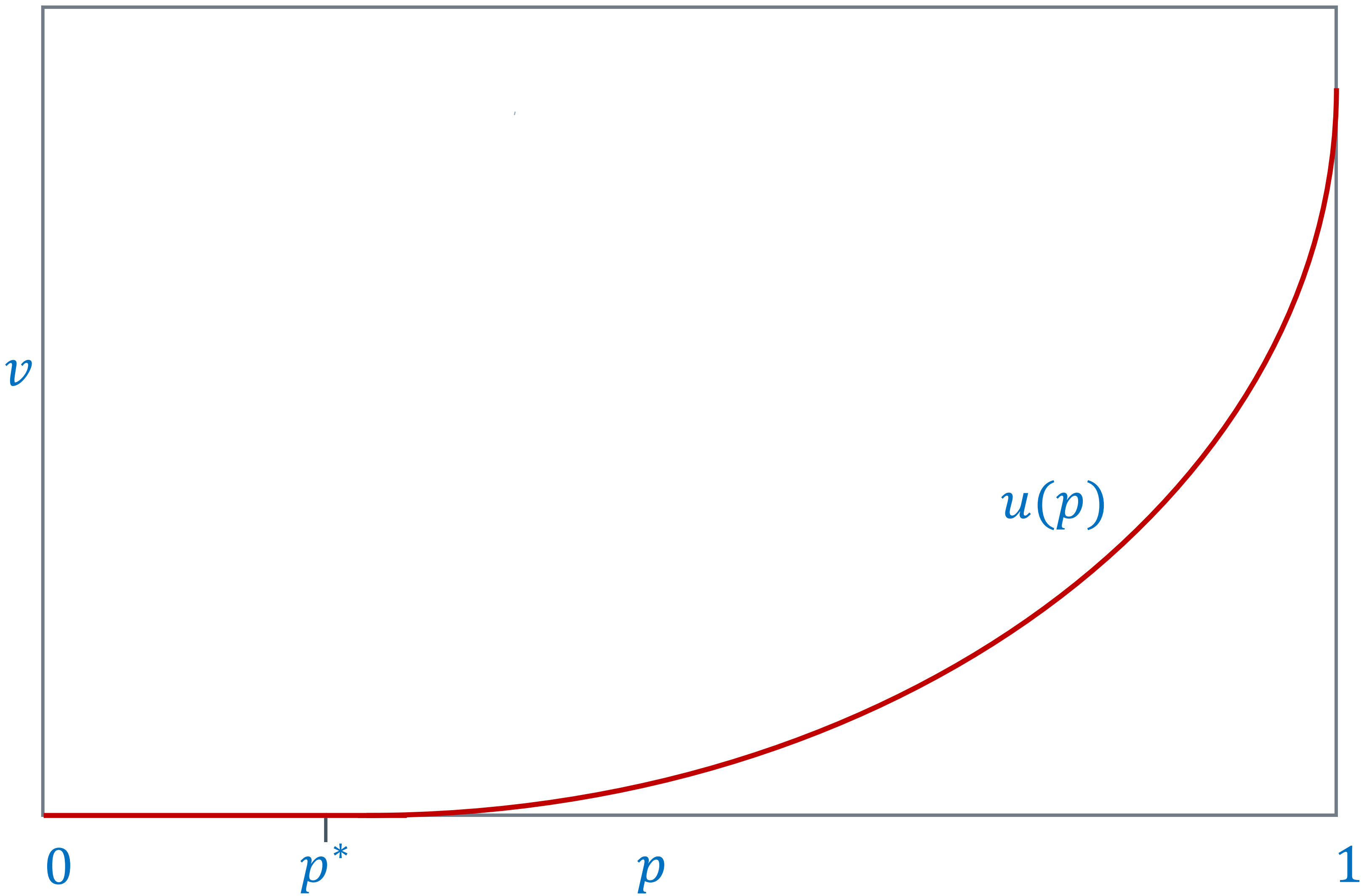
Belief erosion

$$\frac{p_t(s_i)}{1 - p_t(s_i)} = e^{-\lambda t} \times \frac{p(s_i)}{1 - p(s_i)} > \frac{p^*}{1 - p^*}$$

Single firm quitting time



Single firm value function



Single firm problem

Proposition 0: Firm 1 succeeds more often than firm 2 and has a higher payoff.

Two firms

- With one firm, optimal to stay if and only if $p_t > p^*$

- With two firms, still optimal to stay if $p_t > p^*$
- But now may be optimal to stay even if $p_t < p^*$
  - option value of staying to learn rival's information

Asymmetric Information

- Posteriors

$$p(s_1, s_2) = \Pr[\, G \mid s_1, s_2]$$

- Since $q_1 > q_2$

$$p(b_1, b_2) < p(b_1, g_2) < p(g_1, b_2) < p(g_1, g_2)$$

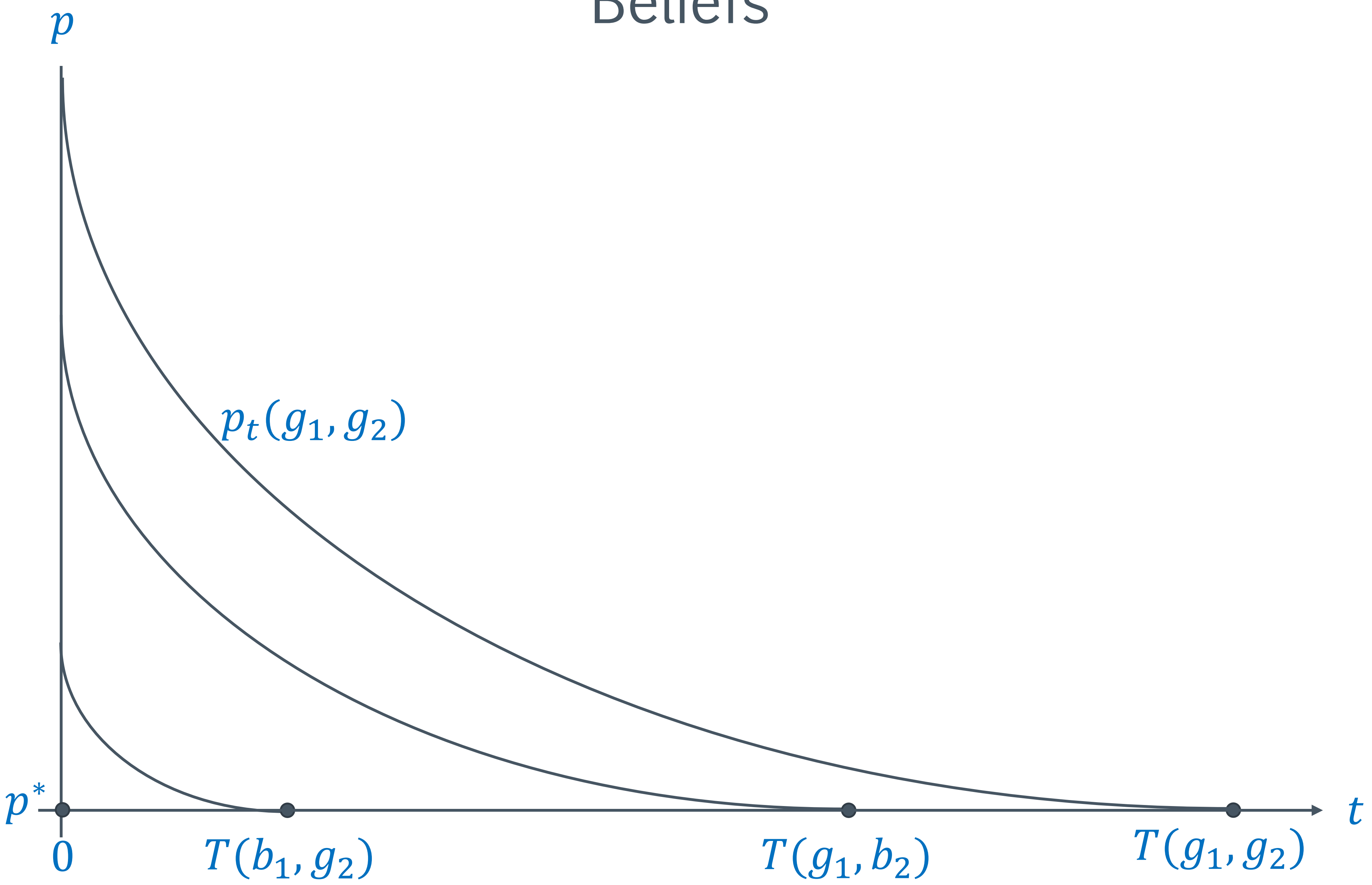
Threshold exit times

- If $p(s_1, s_2) > p^*$, define $T(s_1, s_2)$ by

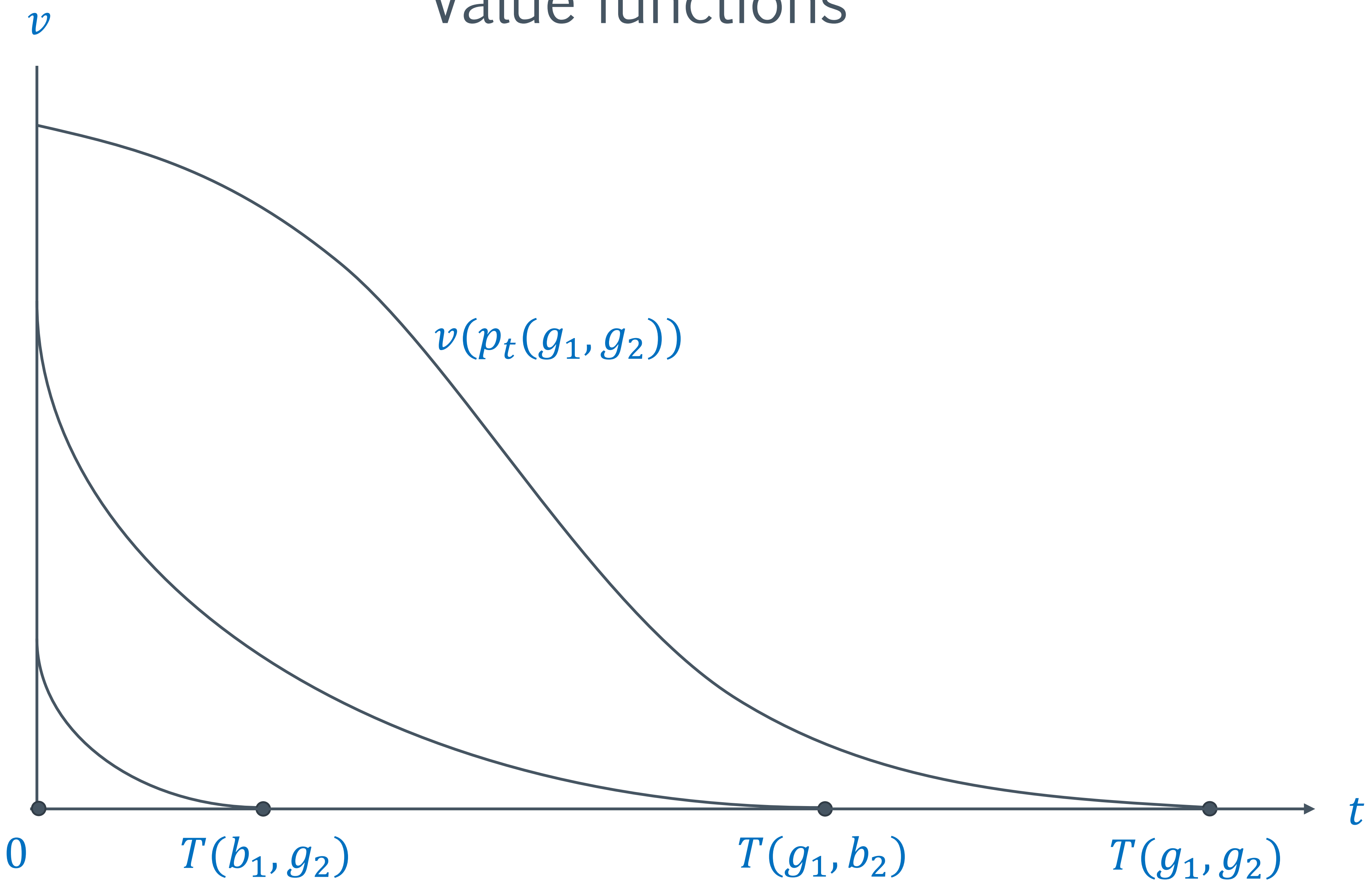
$$e^{-2\lambda T(s_1,s_2)} \times \frac{p(s_1, s_2)}{1 - p(s_1, s_2)} = \frac{p^*}{1 - p^*}$$

- If $p(s_1, s_2) \leq p^*$, define $T(s_1, s_2) = 0$.

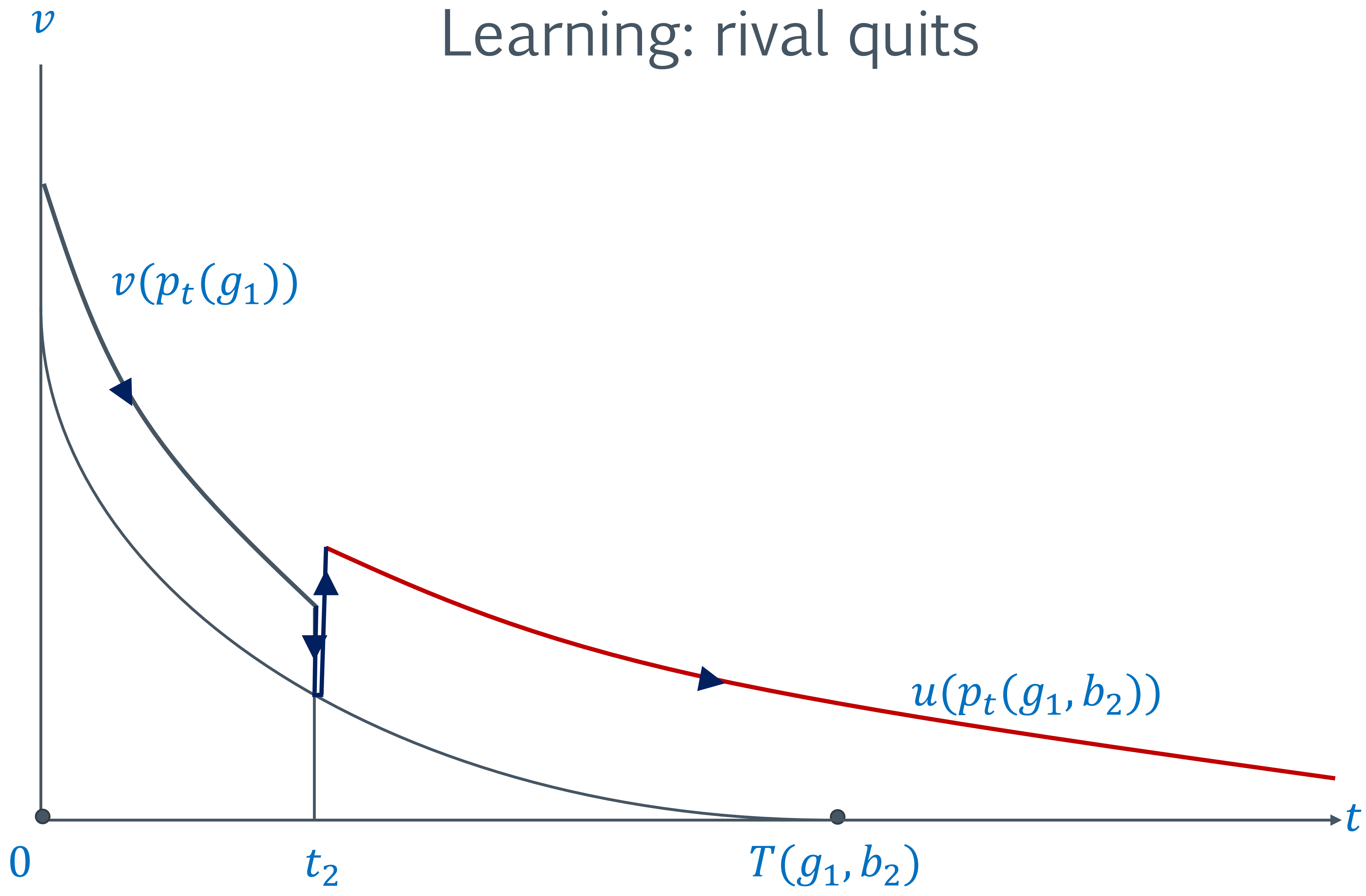
Beliefs



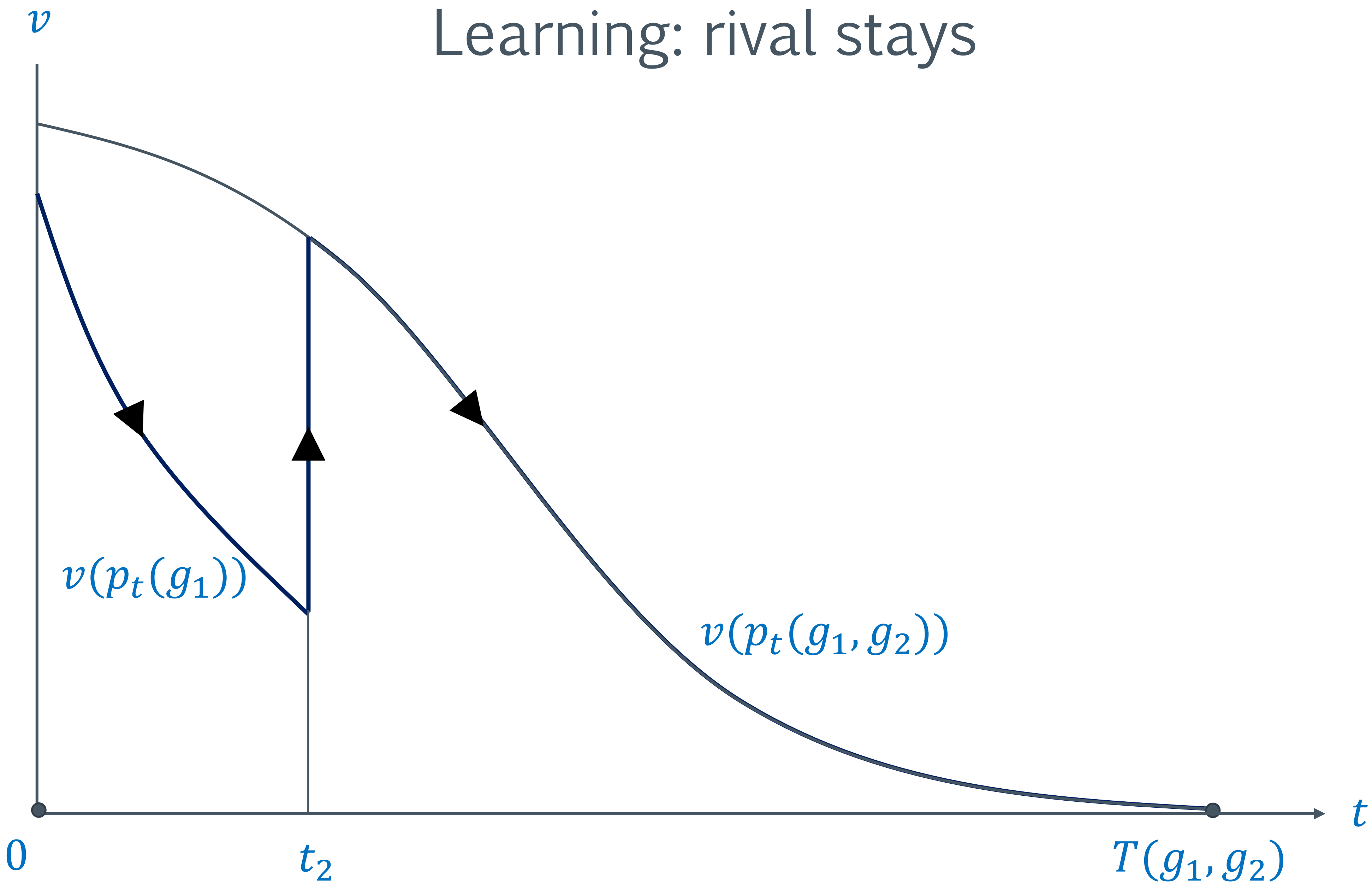
Value functions



Learning: rival quits



Learning: rival stays



Upstart equilibrium

Proposition 1: There is a PBE in which firm 2 wins more often, and has a higher payoff, than firm 1.

Strategies

Two components: (τ_i, σ_i)

› Unilateral exit: $\tau_i(s_i) \in \mathbb{R}_+ \cup \{\infty\}$

› Conditional exit: $\sigma_i(s_i, t_j) \geq t_j + \Delta$

Strategies

Two components: (τ_i, σ_i)

- Unilateral exit: $\tau_i(s_i) \in \mathbb{R}_+ \cup \{\infty\}$

delay

- Conditional exit: $\sigma_i(s_i, t_j) \geq t_j + \Delta$

(Here $\Delta = 0$)

j's exit time

Upstart equilibrium

- Firm 1
  - $\tau_1^*(g_1) = T(g_1, g_2)$ and $\tau_1^*(b_1) = T(b_1)$
  - $\sigma_1^*(g_1, t_2) = \begin{cases} 2T(g_1, b_2) - t_2 & \text{if } t_2 \leq T(g_1, b_2) \\ 2T(g_1, g_2) - t_2 & \text{if } T(g_1, b_2) < t_2 \leq T(g_1, g_2) \end{cases}$
  - $\sigma_1^*(b_1, t_2) = \begin{cases} \max\left(2T(b_1, b_2) - t_2, t_2\right) & \text{if } t_2 \leq T(b_1) \\ t_2 & \text{if } T(b_1) < t_2 \end{cases}$
  - Beliefs: if $t_2 \leq T(g_1, b_2)$, then $\mu_1(s_2 = b_2) = 1$; otherwise 0
- Firm 2
  - $\tau_2^*(g_2) = T(g_1, g_2)$ and $\tau_2^*(b_2) = T(g_1, b_2)$
  - $\sigma_2^*(g_2, t_1) = \begin{cases} 2T(b_1, g_2) - t_1 & \text{if } t_1 \leq T(b_1, g_2) \\ 2T(g_1, g_2) - t_1 & \text{if } T(b_1, g_2) < t_1 \leq T(g_1, g_2) \end{cases}$
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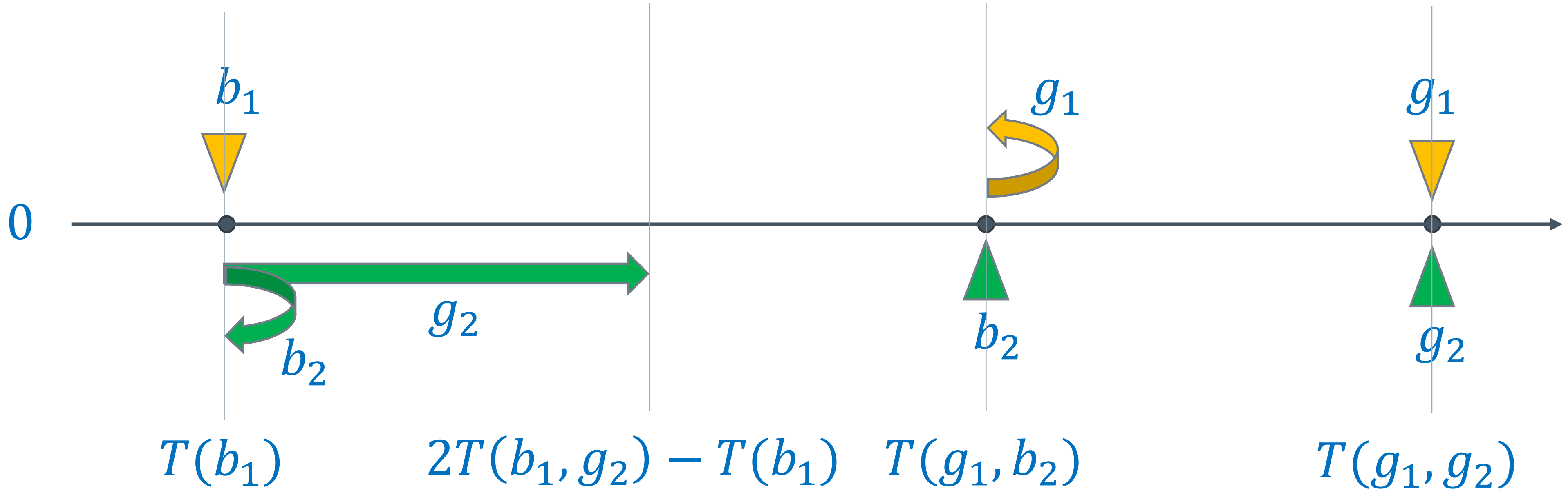
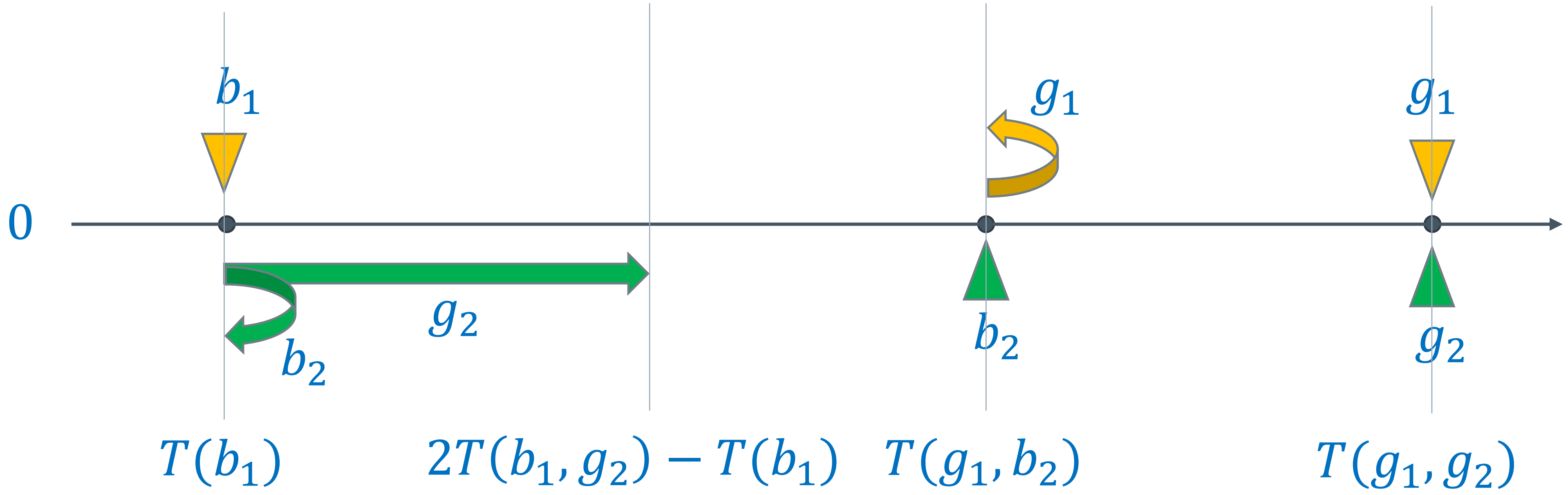
  - Beliefs: if $t_1 \leq T(b_1)$, then $\mu_2(s_1 = b_1) = 1$; otherwise 0

Upstart equilibrium

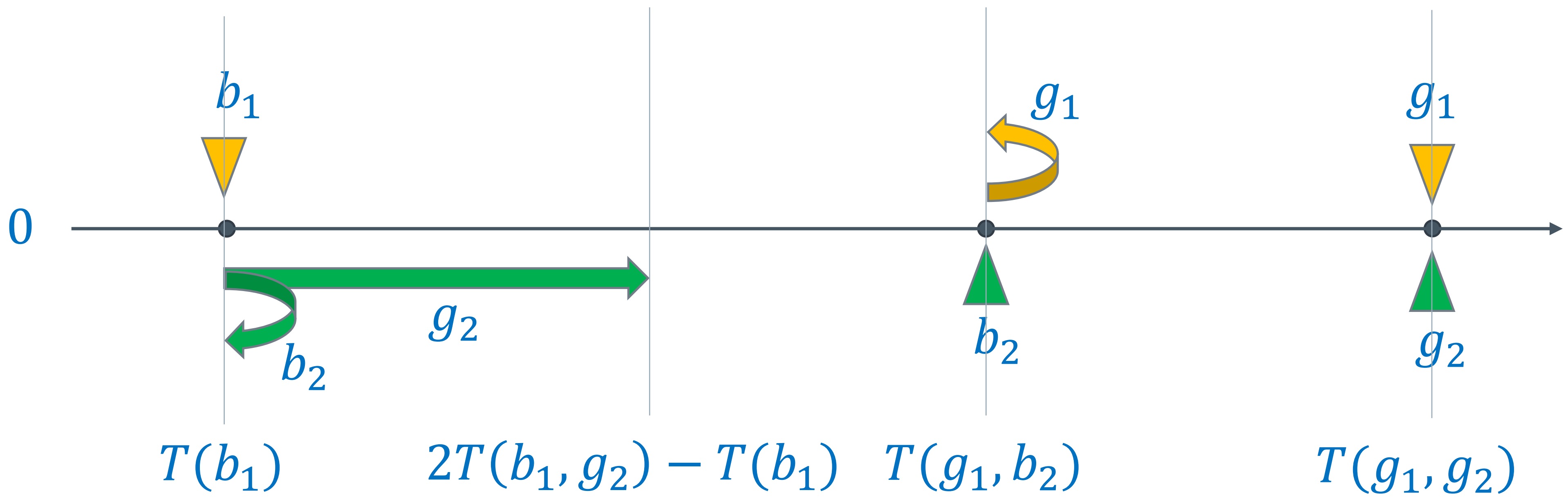


Upstart equilibrium



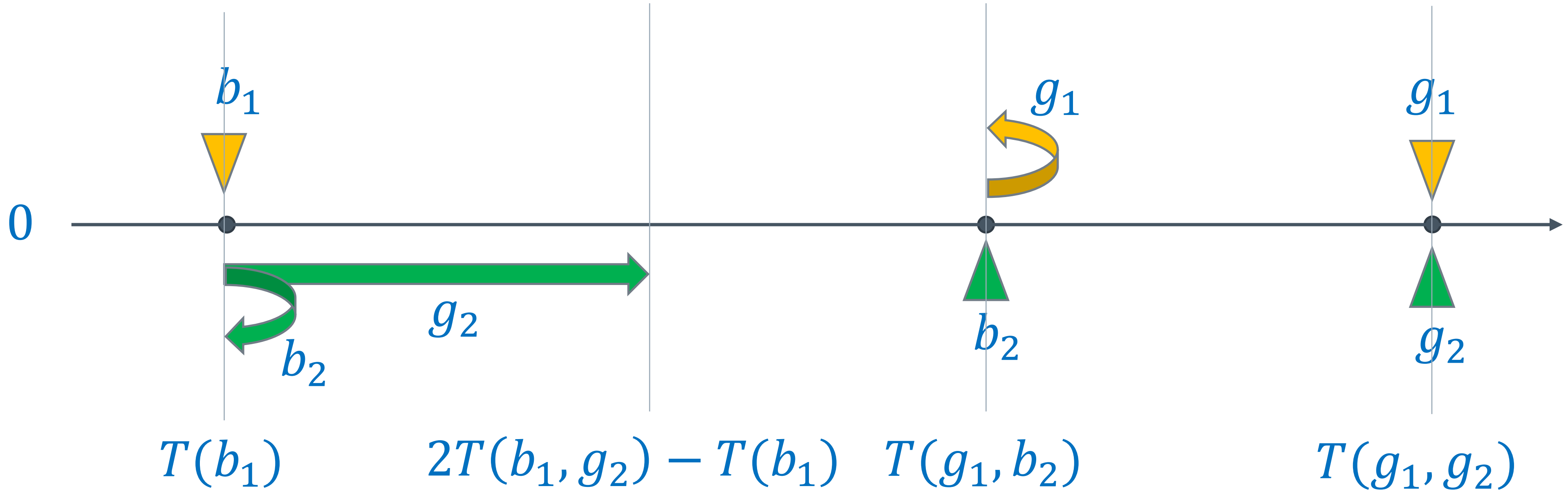
b_1 exits unilaterally at $T(b_1)$ while g_1 stays

Upstart equilibrium



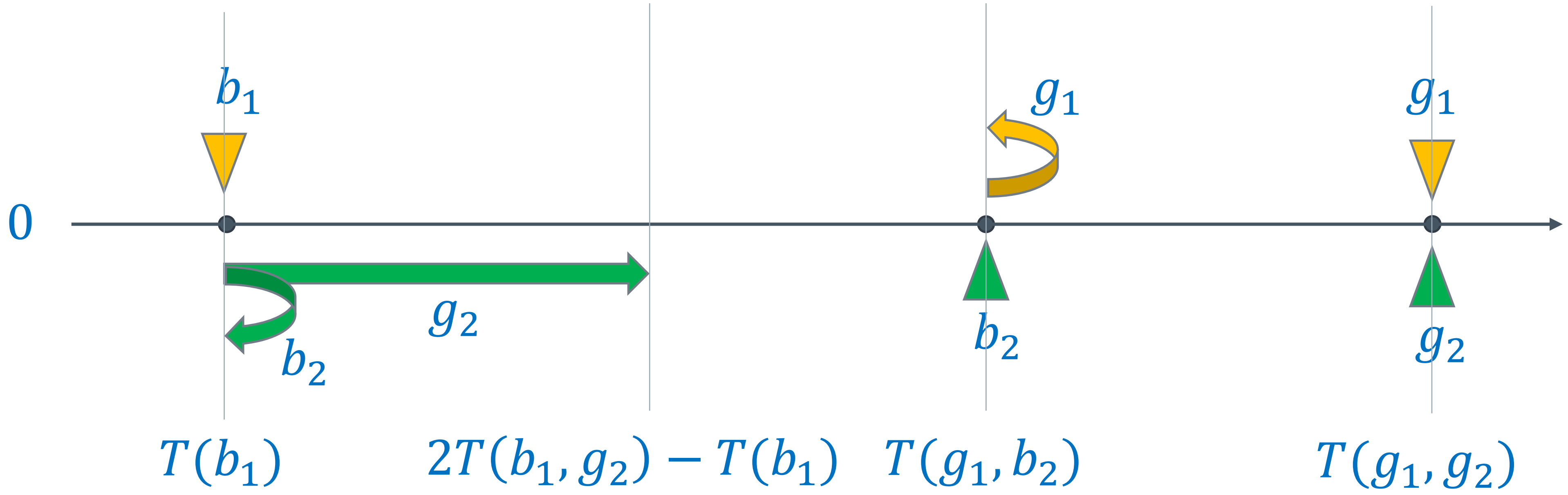
Firm 2 learns 1's signal at $T(b_1)$ and plays a best response

Upstart equilibrium



g_1 learns 2's signal at $T(g_1, b_2)$ and plays a best response

Upstart equilibrium



b_1 cannot learn 2's signal before $T(g_1, b_2)$ and this is too late.
Staying after $T(b_1)$ based on own information is not optimal.

Upstart equilibrium

If signals are:

- (b_1, b_2), 1 exits at $T(b_1)$ and 2 follows immediately
- (b_1, g_2), 1 exits at $T(b_1)$ and 2 exits at $2T(b_1, g_2) - T(b_1)$
- (g_1, b_2), 2 exits at $T(g_1, b_2)$ and 1 follows immediately
- (g_1, g_2), both stay until $T(g_1, g_2)$

Upstart equilibrium

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- (b_1, b_2), 1 exits at $T(b_1)$ and 2 follows immediately
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- (g_1, g_2), both stay until $T(g_1, g_2)$

Equilibrium payoffs

- $\Pi_2^* - \Pi_1^* =$ R&D payoff in $[T(b_1), 2T(b_1, g_2) - T(b_1)]$

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- $\Pi_2^* > \Pi_1^*$
  - if $q_2 > \frac{1}{2}$ & $p(b_1, g_2) > p^*$ so $T(b_1) < T(b_1, g_2)$

Equilibrium payoffs

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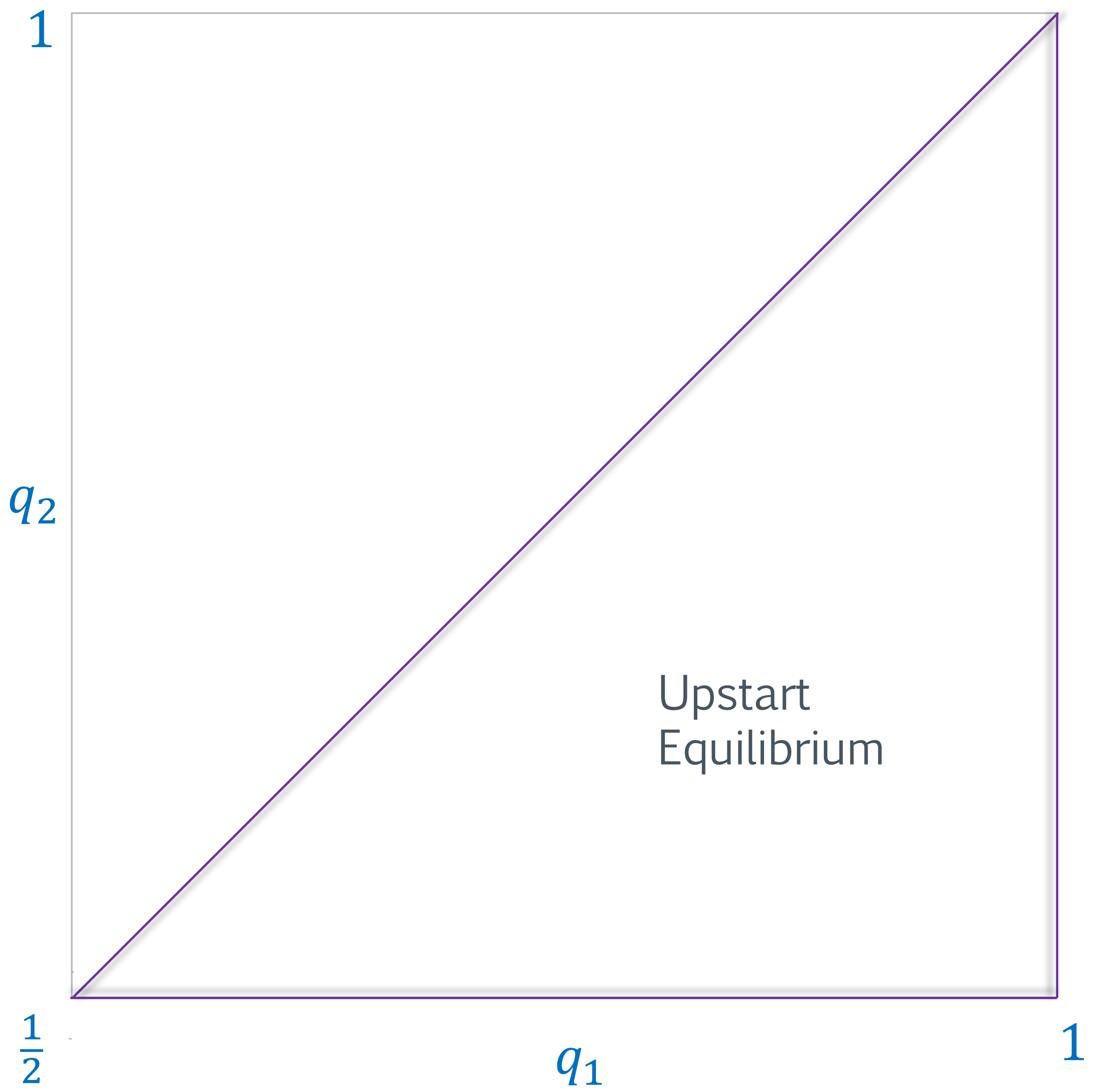
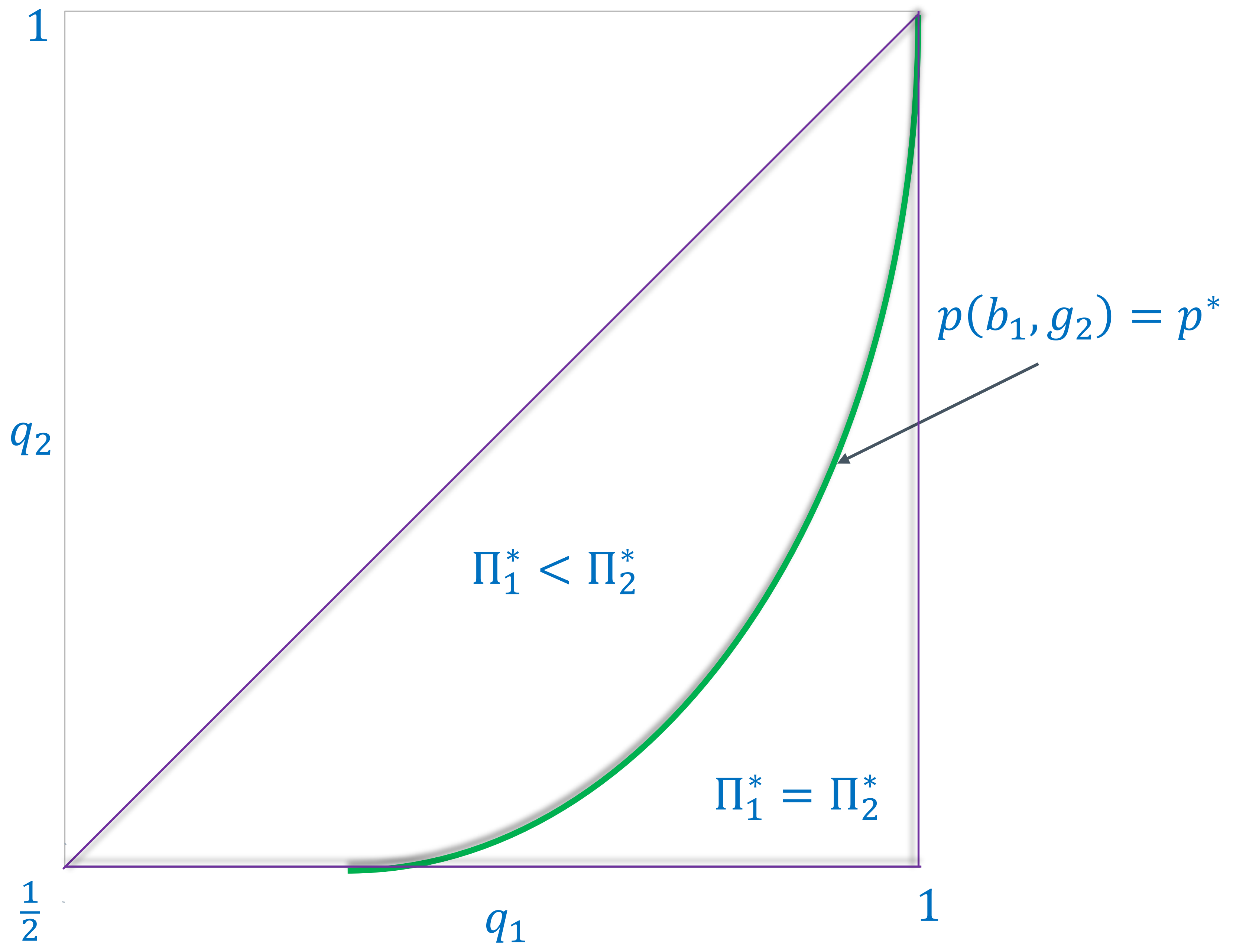
- $\Pi_2^* > \Pi_1^*$
  - if $q_2 > \frac{1}{2}$ & $p(b_1, g_2) > p^*$ so $T(b_1) < T(b_1, g_2)$

- $\Pi_2^* = \Pi_1^*$
  - if firm 2 is completely uninformed $(q_2 = \frac{1}{2})$
  - if firm 1 is perfectly informed $(q_1 = 1)$

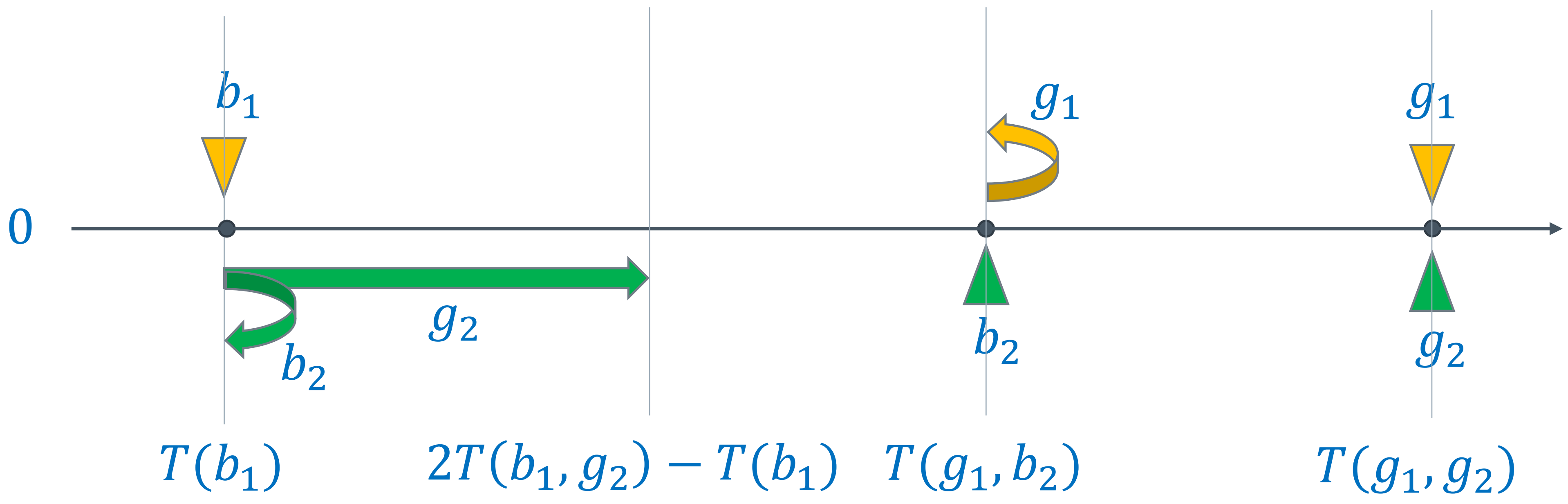

1
q_2
Upstart
Equilibrium
$\frac{1}{2}$
q_1
1


1
q_2
$\frac{1}{2}$
q_1
1
$p(b_1, g_2) = p^*$
$\Pi_1^* < \Pi_2^*$
$\Pi_1^* = \Pi_2^*$

Learning in equilibrium

- Firm 2 with either b_2 or g_2 learns firm 1's signal
- Only firm 1 with g_1 learns firm 2's signal
- Firm 1 with b_1 exits too early to learn 2's signal
  - has ex post regret if $s_2 = g_2$

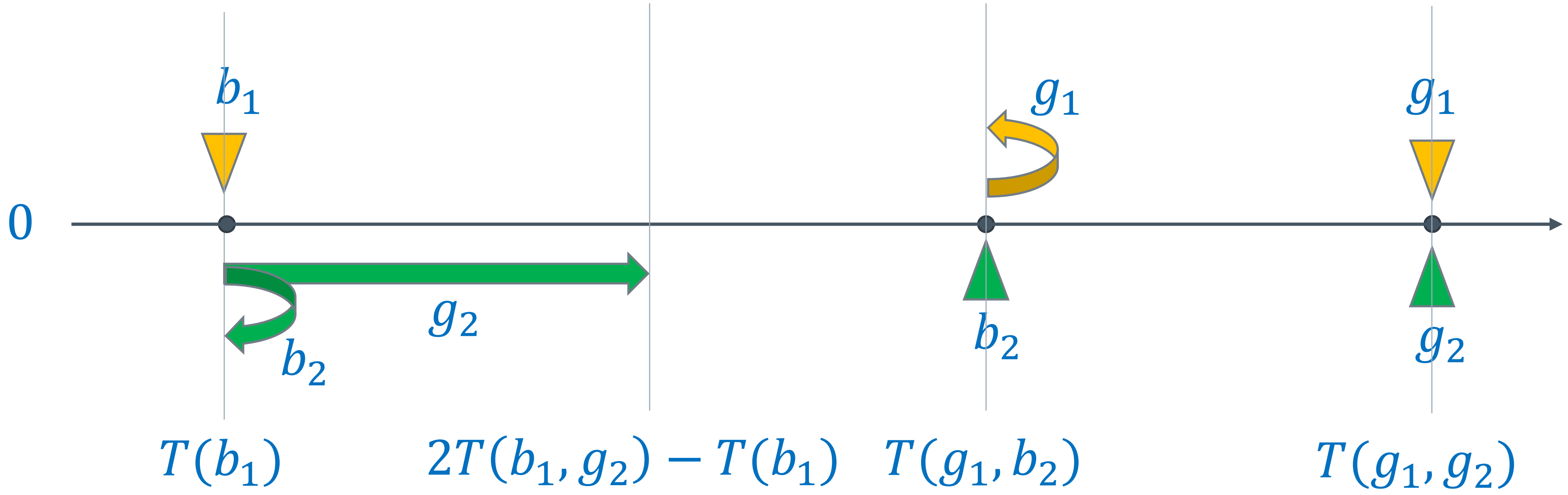
Upstart equilibrium



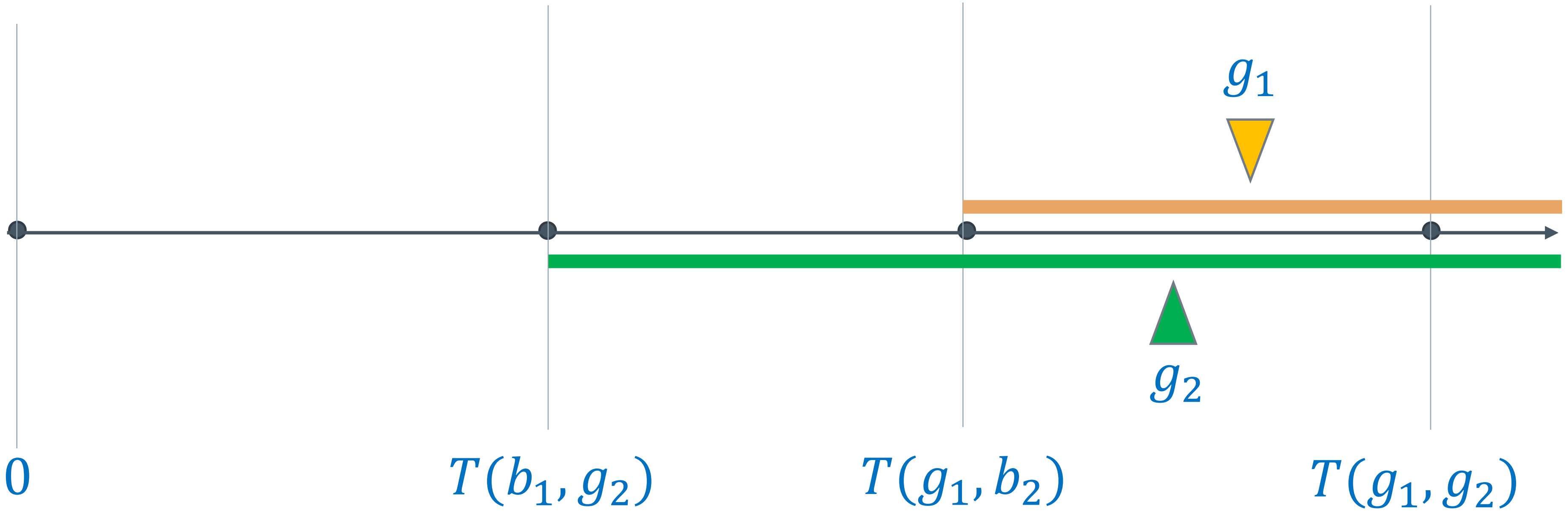
Uniqueness

Proposition 2: When firm 1 is much better-informed, there is a unique Nash outcome.

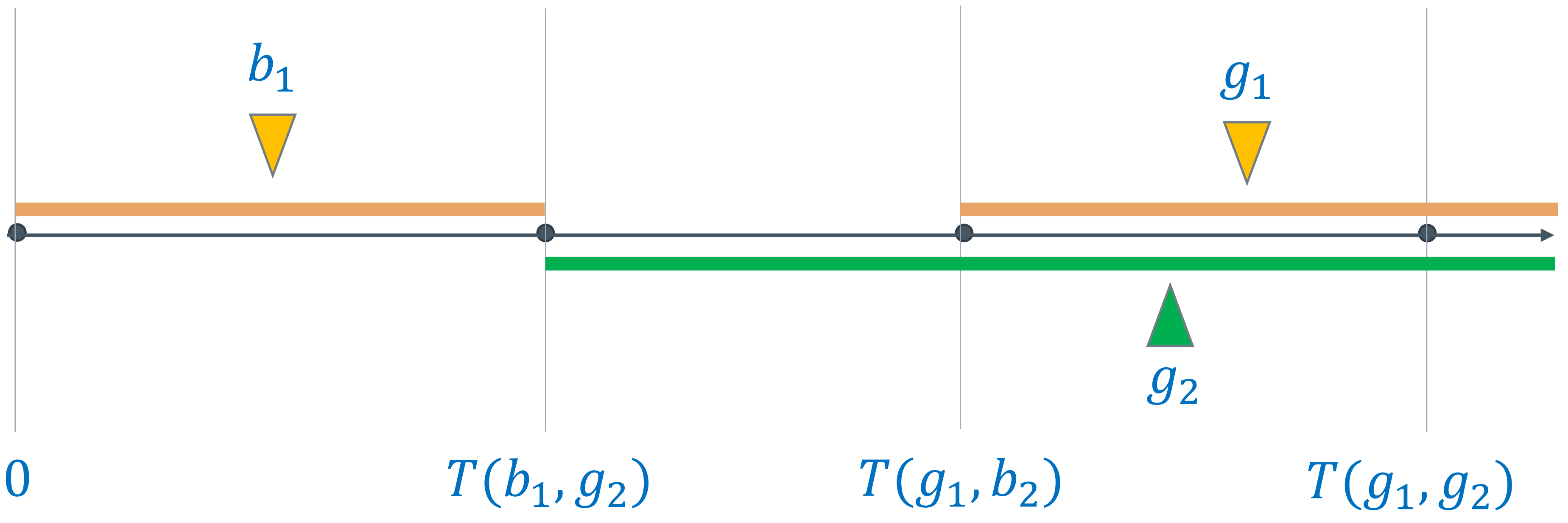
Upstart equilibrium



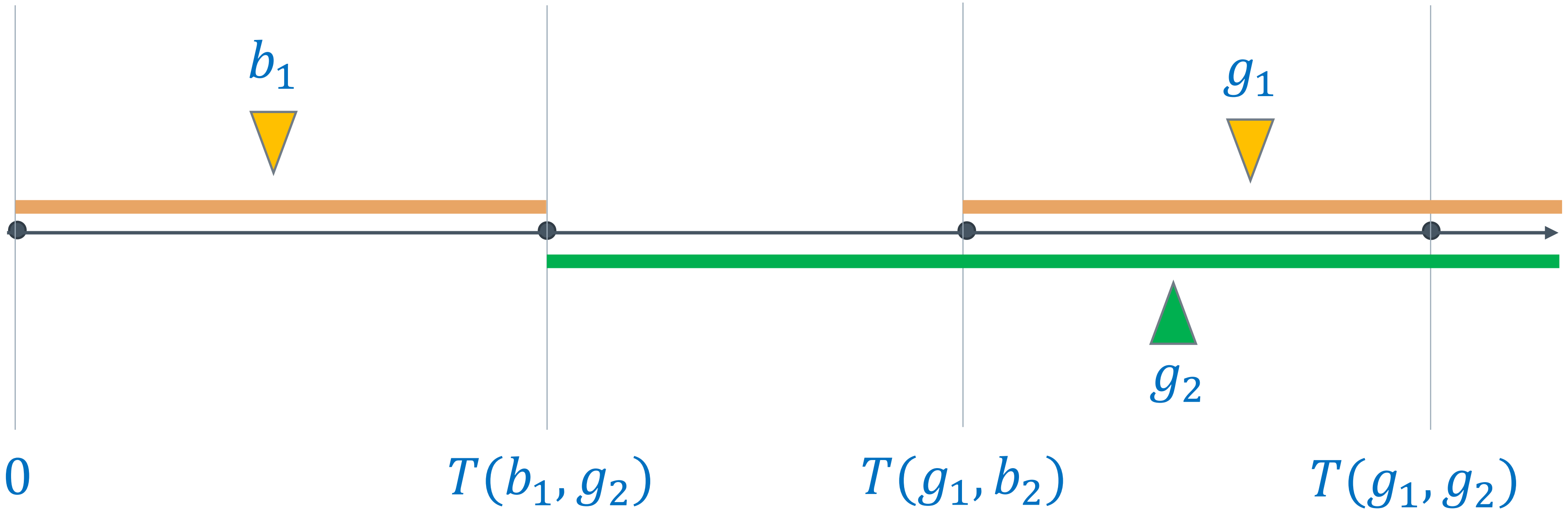
IEDS Round 1W: g_1, g_2



Round 2S: b_1

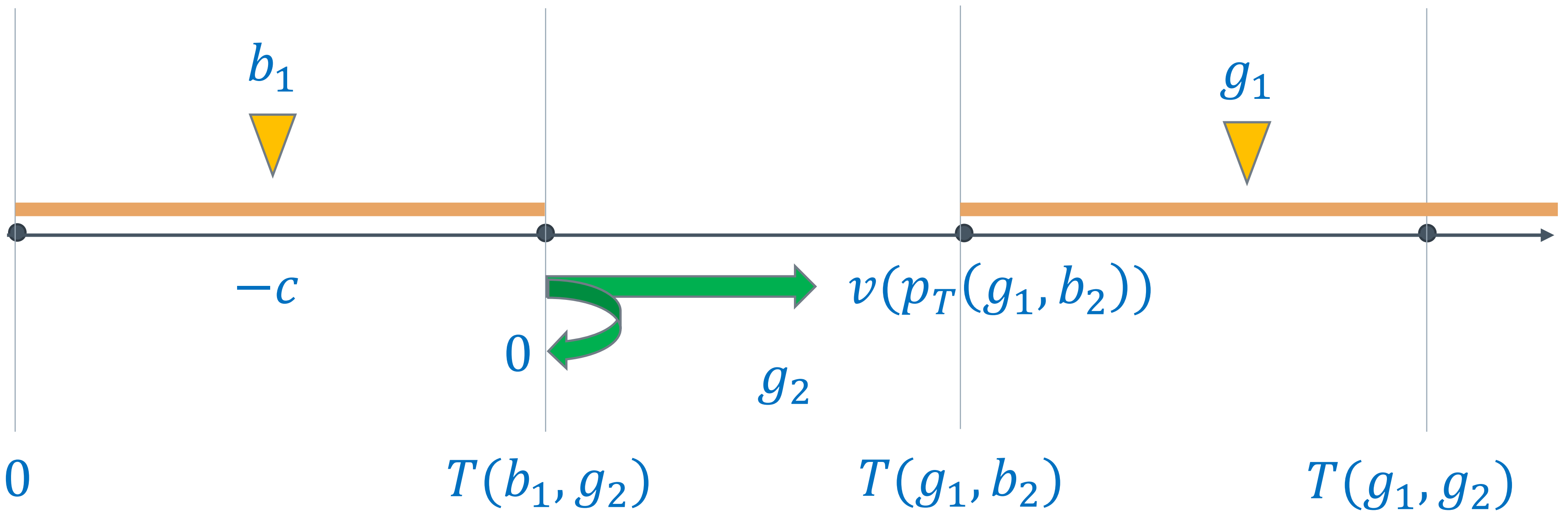


Round 3S: b_2



Clearly dominated to exit before $T(b_1, b_2)$.
By staying until $T(b_1, g_2)$, b_2 can learn firm 1's signal

Round 3S: b_2



A lower bound to payoff from staying until $T(b_1, g_2)$

Round 3S: b_2

b_2's payoff at any T from waiting to learn 1's signal

$$\underbrace{\lambda m \int_{T}^{T(b_1,g_2)} e^{-rt} \Pr[\mathcal{S}_0(t)](p_t(b_2) - p^*)dt}_{<0?} +$$

$$\Pr[g_1|b_2] \times \underbrace{\lambda m \int_{T(b_1,g_2)}^{T(g_1,b_2)} e^{-rt} \Pr[\mathcal{S}_0(t)](p_t(g_1,b_2) - p^*)dt}_{>0}$$

Note: $T \in (T(b_1,b_2), T(b_1,g_2))$

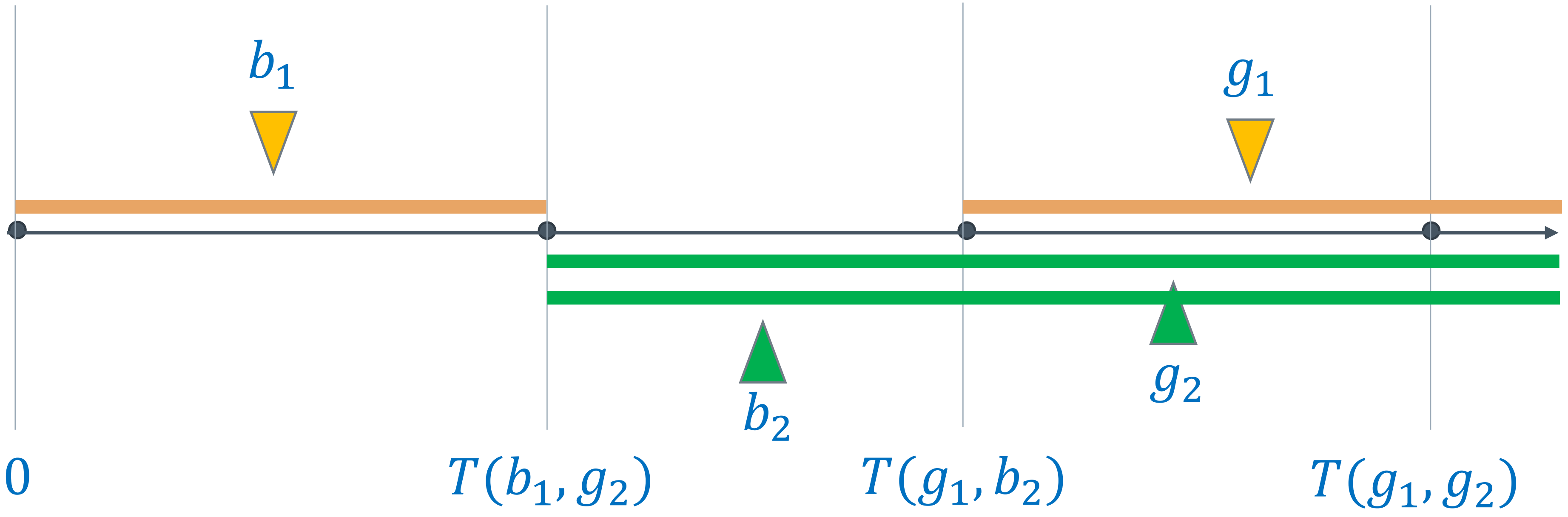
Round 3S: b_2

As $q_2 \to \frac{1}{2}$, $T(b_1, g_2) \to T(b_1, b_2)$, and so for $T > T(b_1, b_2)$,

$$\underbrace{\lambda m \int_{T}^{T(b_1,g_2)} e^{-rt} \Pr[\mathcal{S}_0(t)](p_t(b_2) - p^*)dt}_{\to 0} +$$

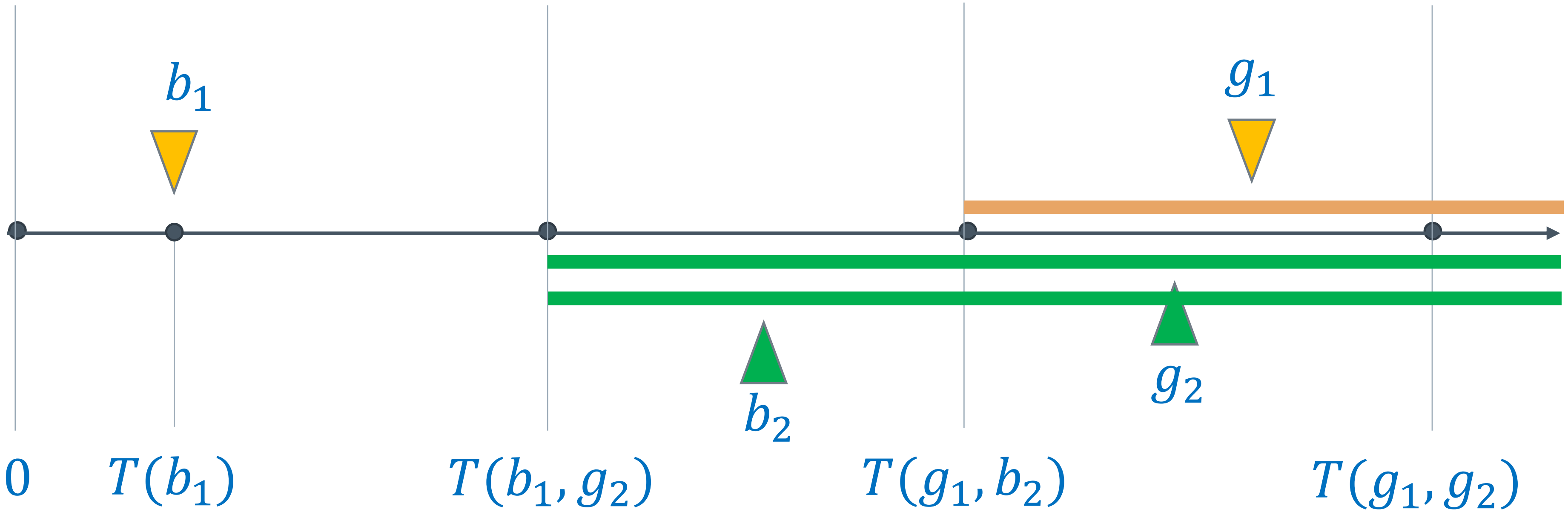
$$\Pr[g_1|b_2] \times \underbrace{\lambda m \int_{T(b_1,g_2)}^{T(g_1,b_2)} e^{-rt} \Pr[\mathcal{S}_0(t)](p_t(g_1, b_2) - p^*)dt}_{>0}$$

Round 3S: b_2



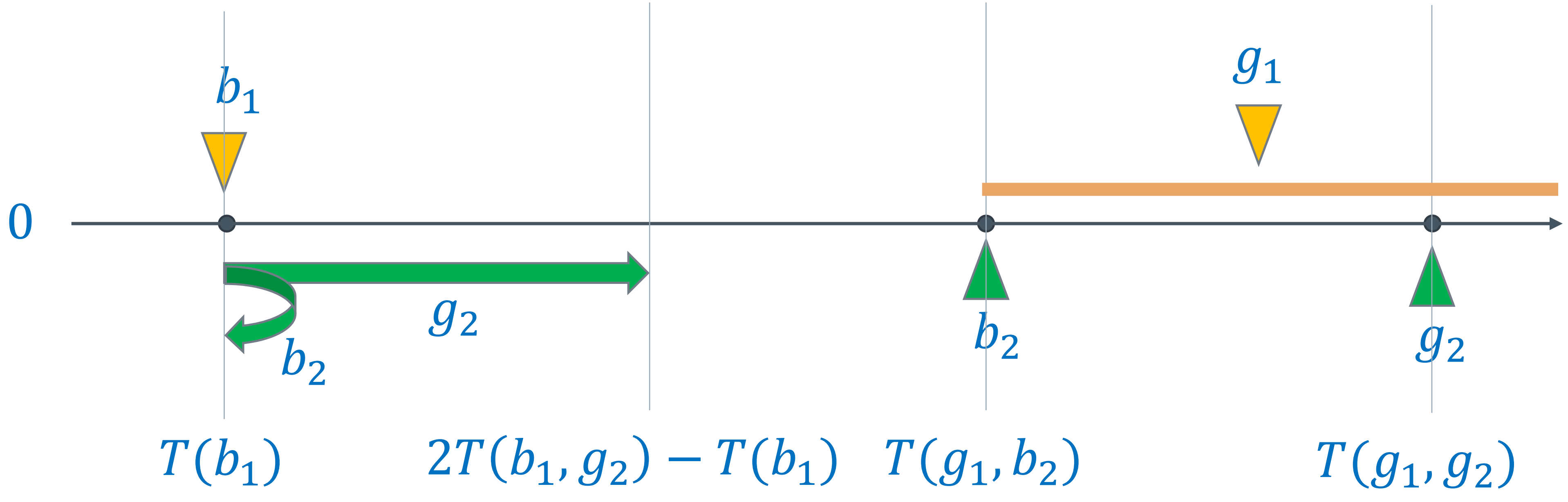
For q_2 small, quitting before $T(b_1, g_2)$ is strictly dominated for b_2.

Round 4S: b_1



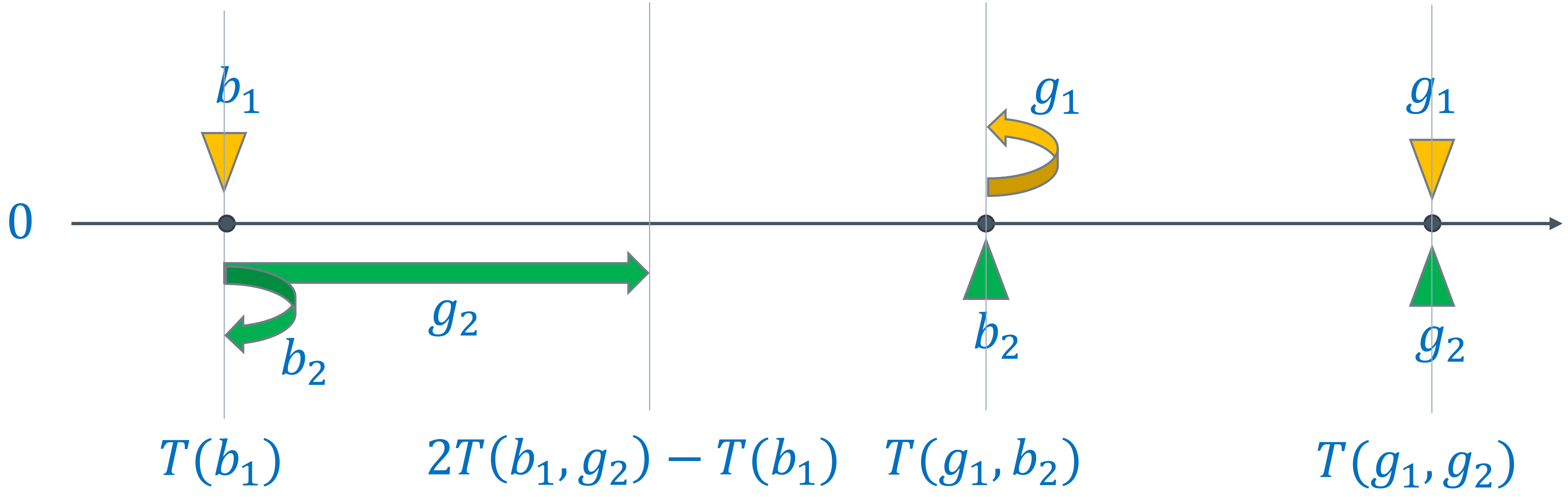
Since neither b_2 nor g_2 will quit before $T(b_1, g_2)$, b_1 quits at $T(b_1)$.

Round 5S/W: b_2



Optimal response for b_2 at time 0.

Round 6S: g_1



Optimal response for g_1 at time $T(g_1, b_2)$.

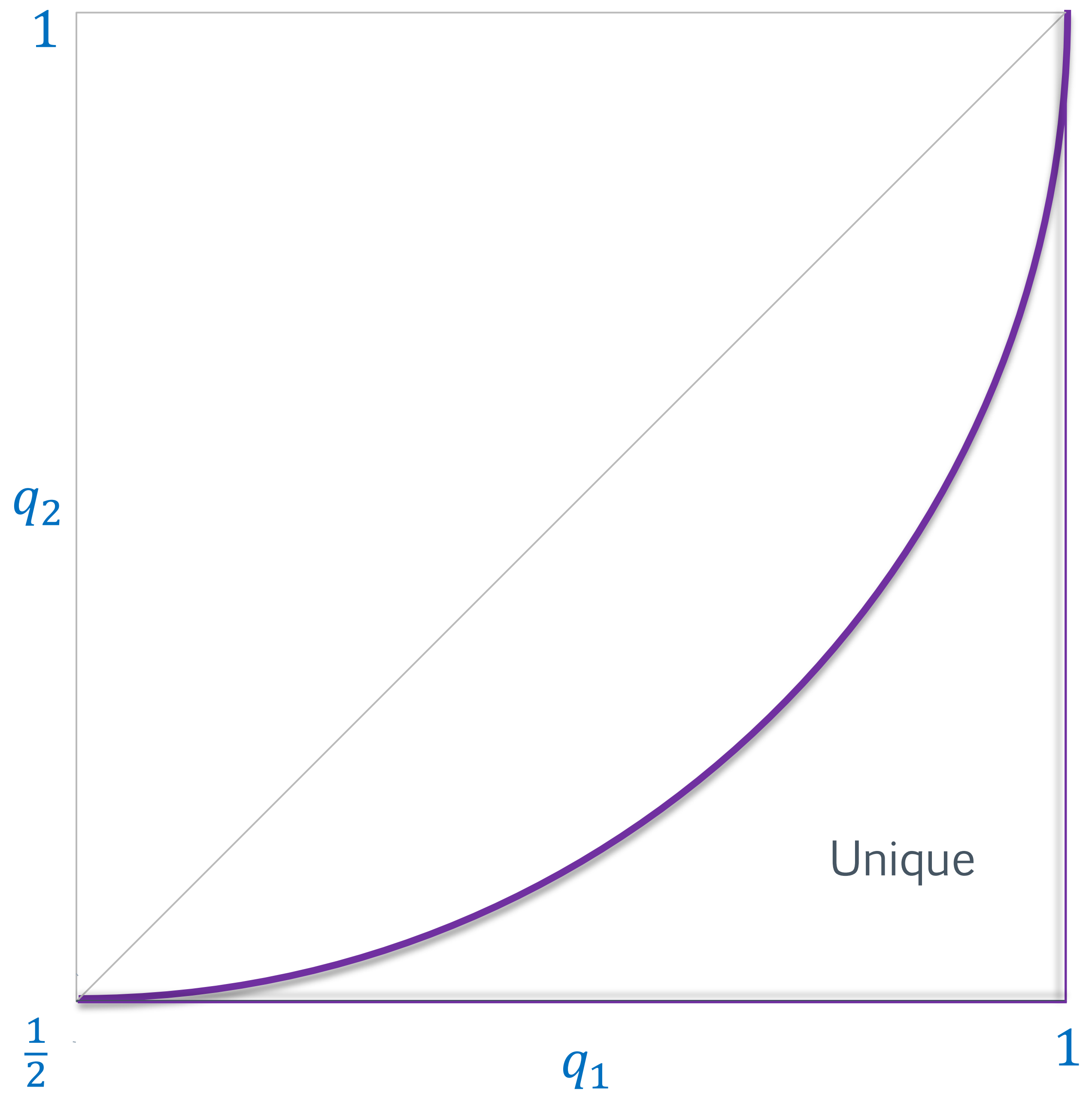
Last step

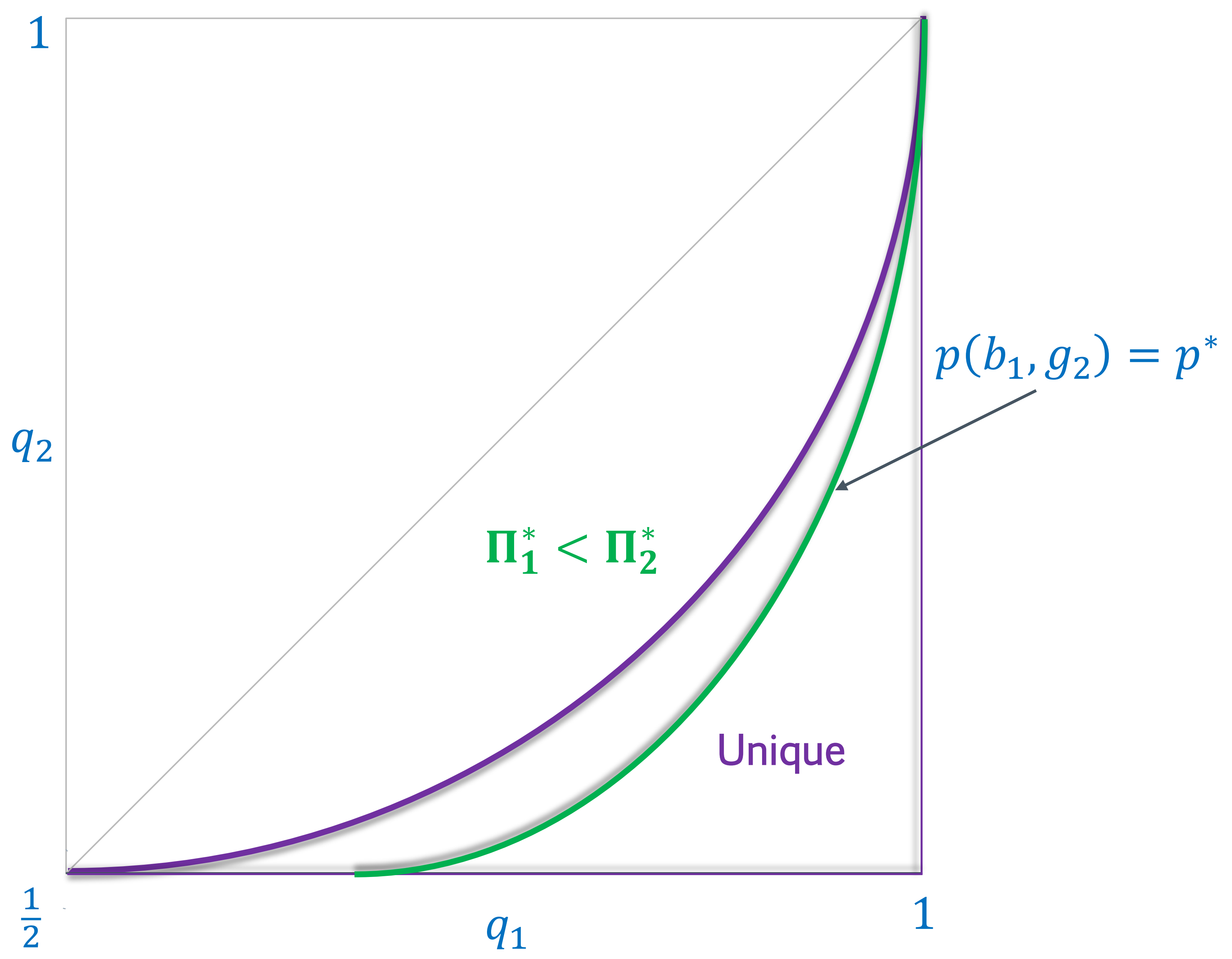
- Iterated elimination of W/S strategies leaves a single outcome
- Check that no other equilibrium outcome could have been eliminated at a W stage
- Note that q_2 small—and hence $T(b_1, g_2)$ small—is used in round 3S
- Also, unique result of IE conditional dominance

Upstart equilibrium

Proposition 1: There is a PBE in which firm 2 wins more often, and has a higher payoff, than firm 1.

Proposition 2: When firm 1 is much better-informed, there is a unique Nash outcome.


1
q_2
Unique
$\frac{1}{2}$
q_1
1

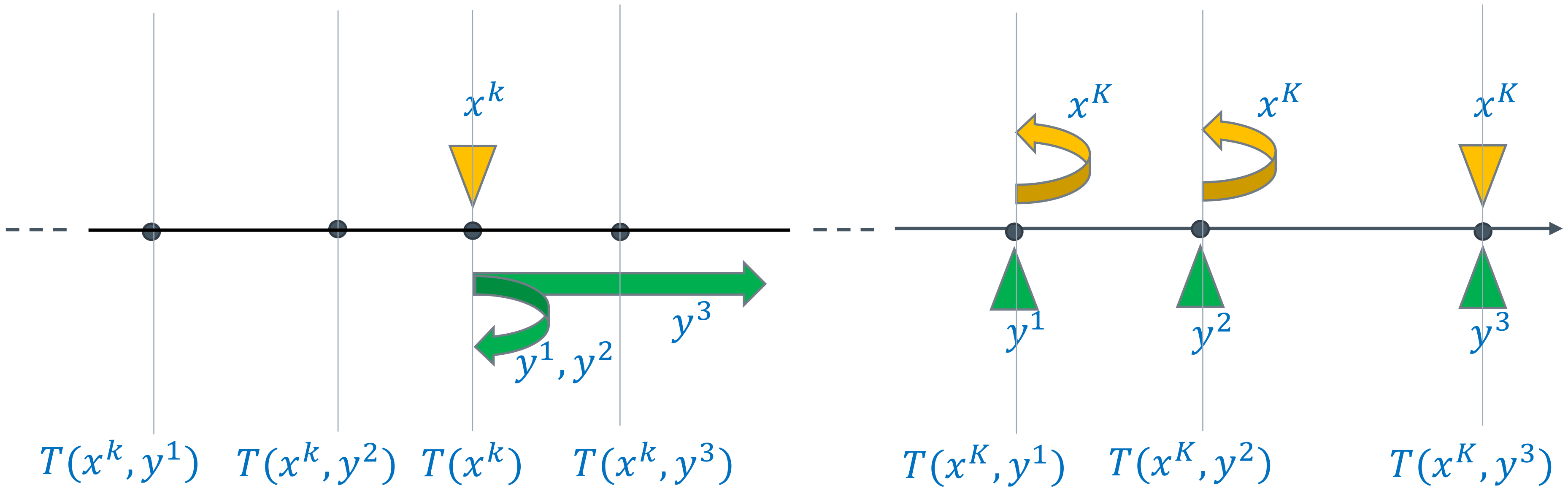


1
q_2
$\frac{1}{2}$
q_1
1
$p(b_1, g_2) = p^*$
$\Pi_1^* < \Pi_2^*$
Unique

Many signals

- $S_1 = \{x^1, x^2, \dots, x^K\}$ and $S_2 = \{y^1, y^2, \dots, y^L\}$
- MLRP
- Firm 2's signals are poor:
  $p(x^k, y^1) < \cdots < p(x^k, y^L) < p(x^{k+1}, y^1) < \cdots < p(x^{k+1}, y^L)$

Many signals



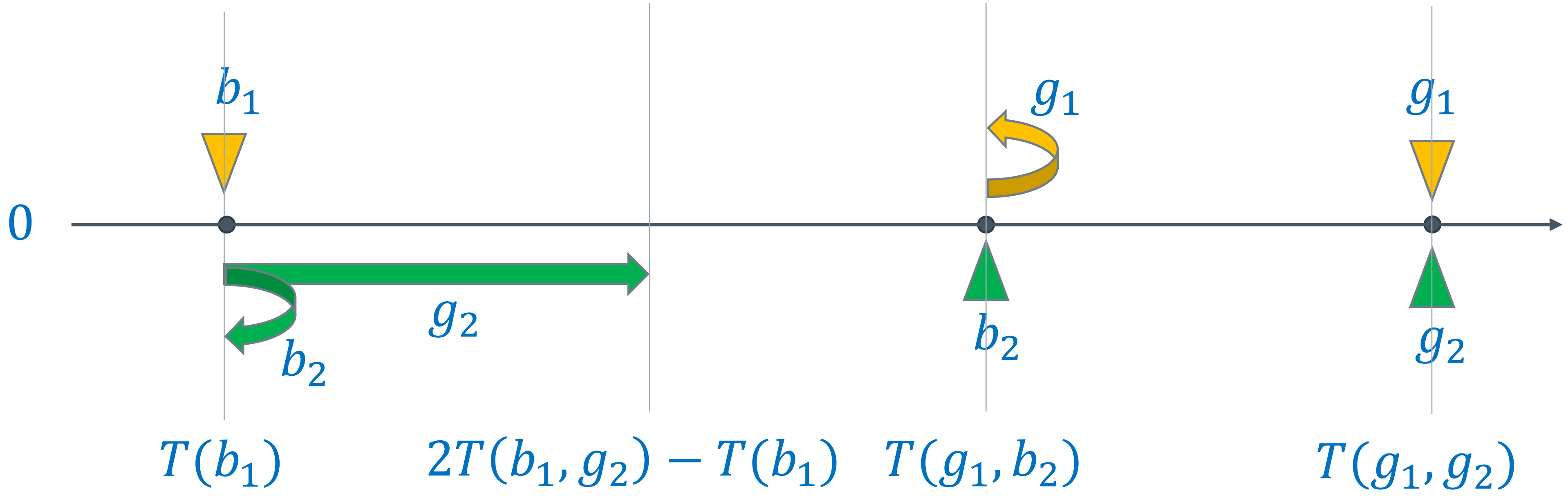
Stage $k < K$

Stage K

Why?

- Known reasons
  - Second mover advantage
  - Negative value of information

Second-mover advantage?



Timing is endogenous: b_1 moves first, g_1 moves second.

Why?

- Known reasons
  - ~~Second mover advantage~~
  - Negative value of information

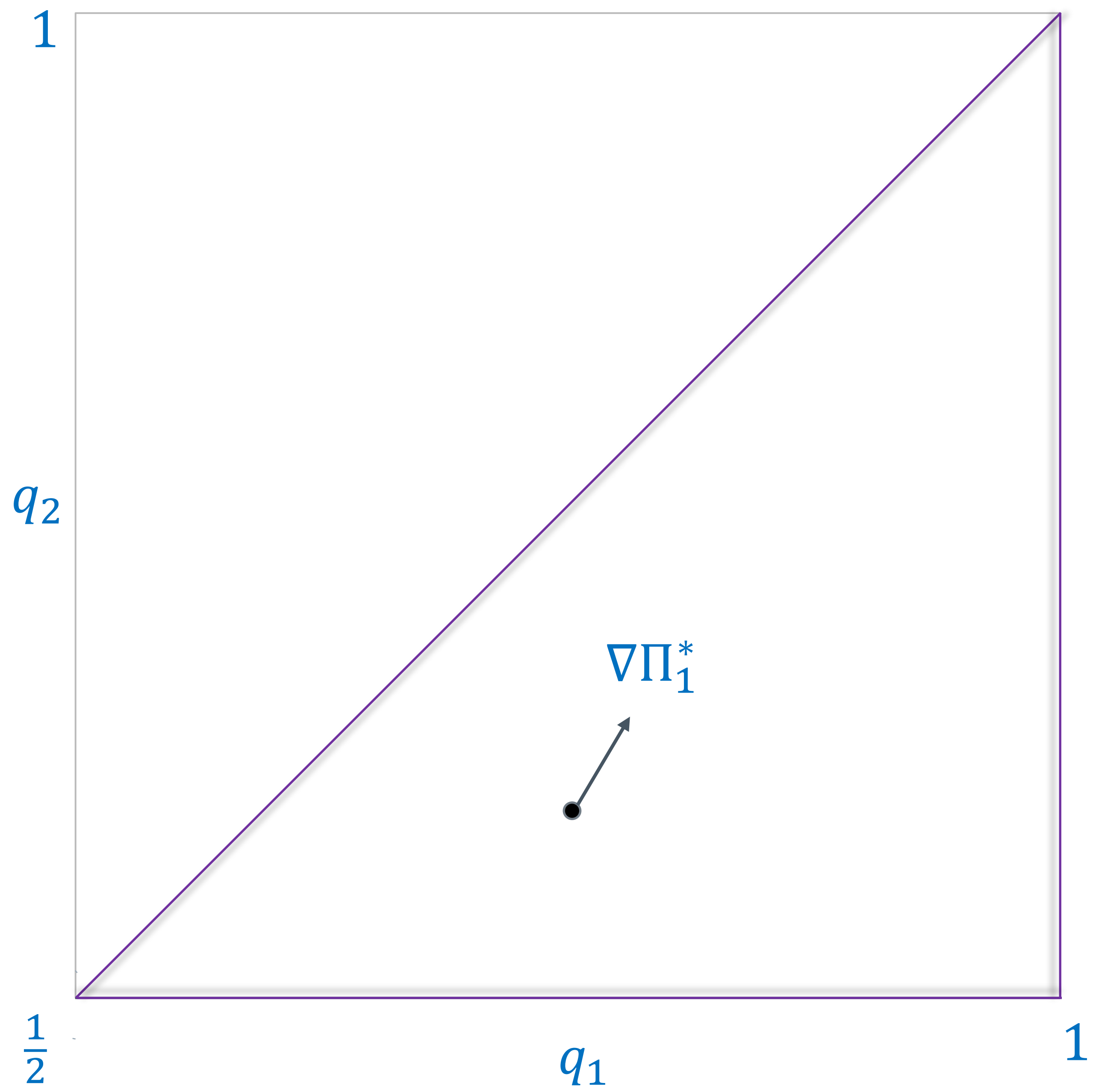
Value of information

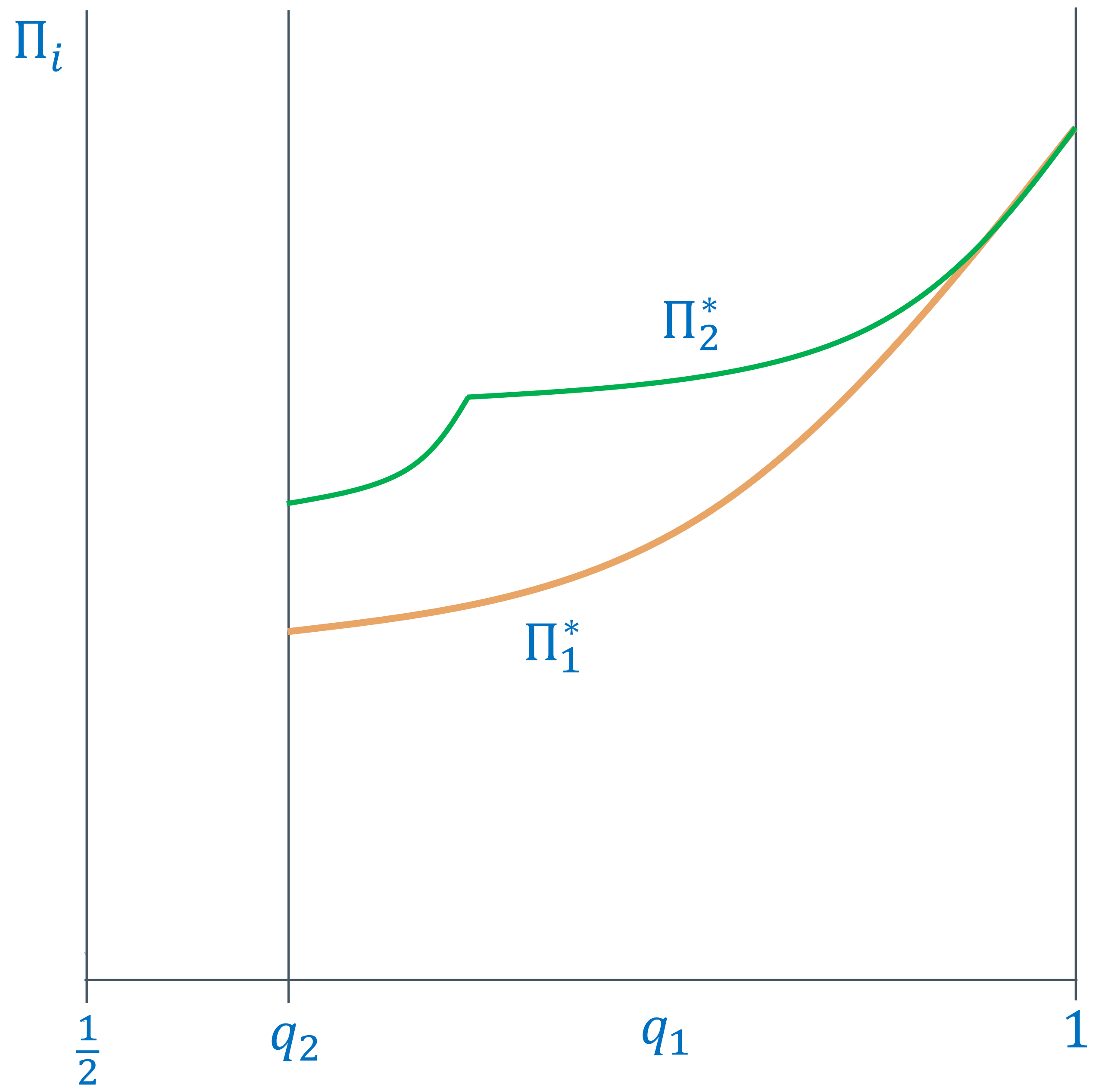
Proposition 3: If $q_1 > q_2$, the value of information is positive:

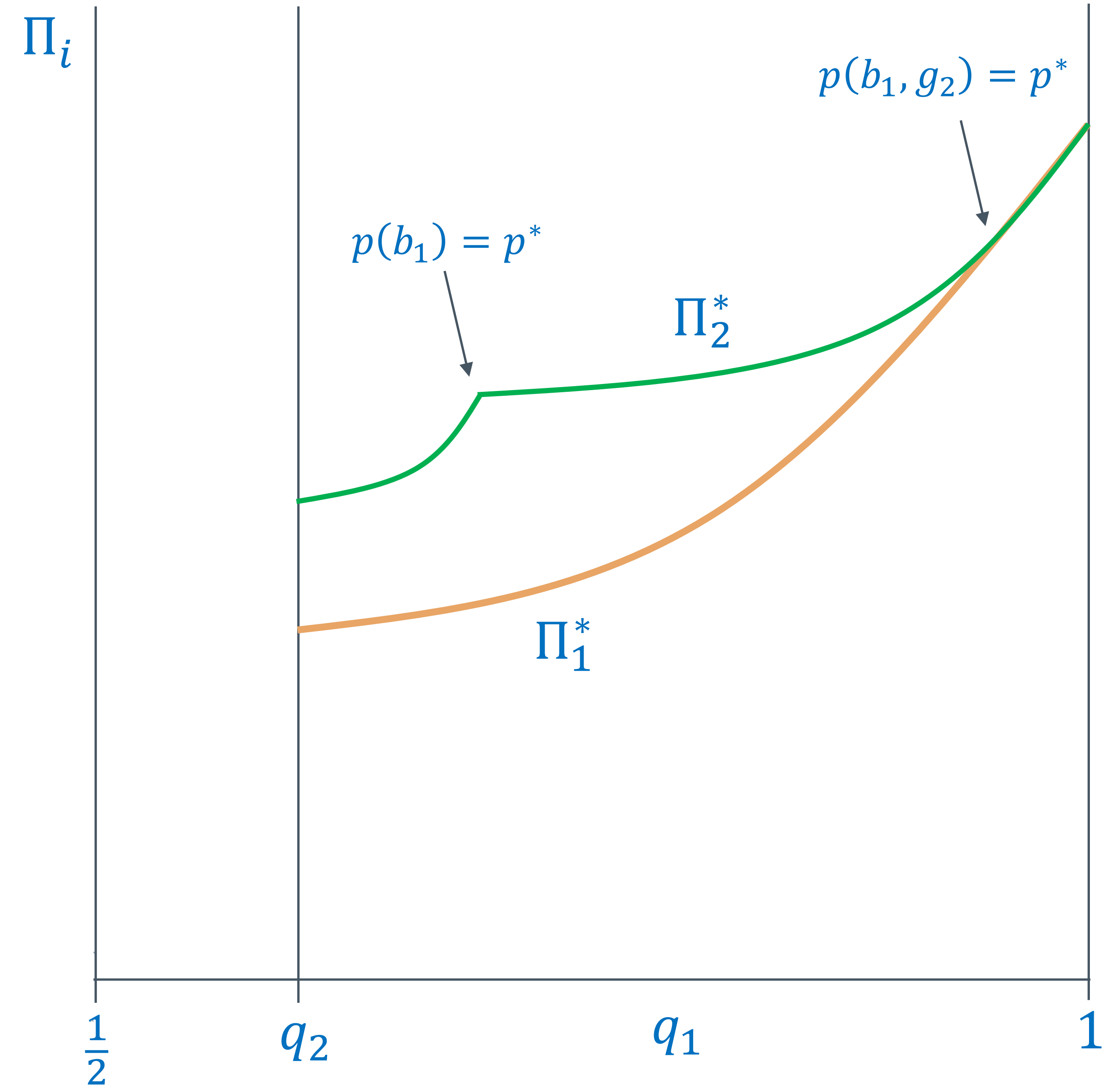
$$\frac{\partial \Pi_1^*}{\partial q_1} > 0 \quad \& \quad \frac{\partial \Pi_2^*}{\partial q_2} > 0$$

Also,

$$\frac{\partial \Pi_1^*}{\partial q_2} > 0$$


1
q_2
$\nabla\Pi_1^*$
$\frac{1}{2}$
q_1
1

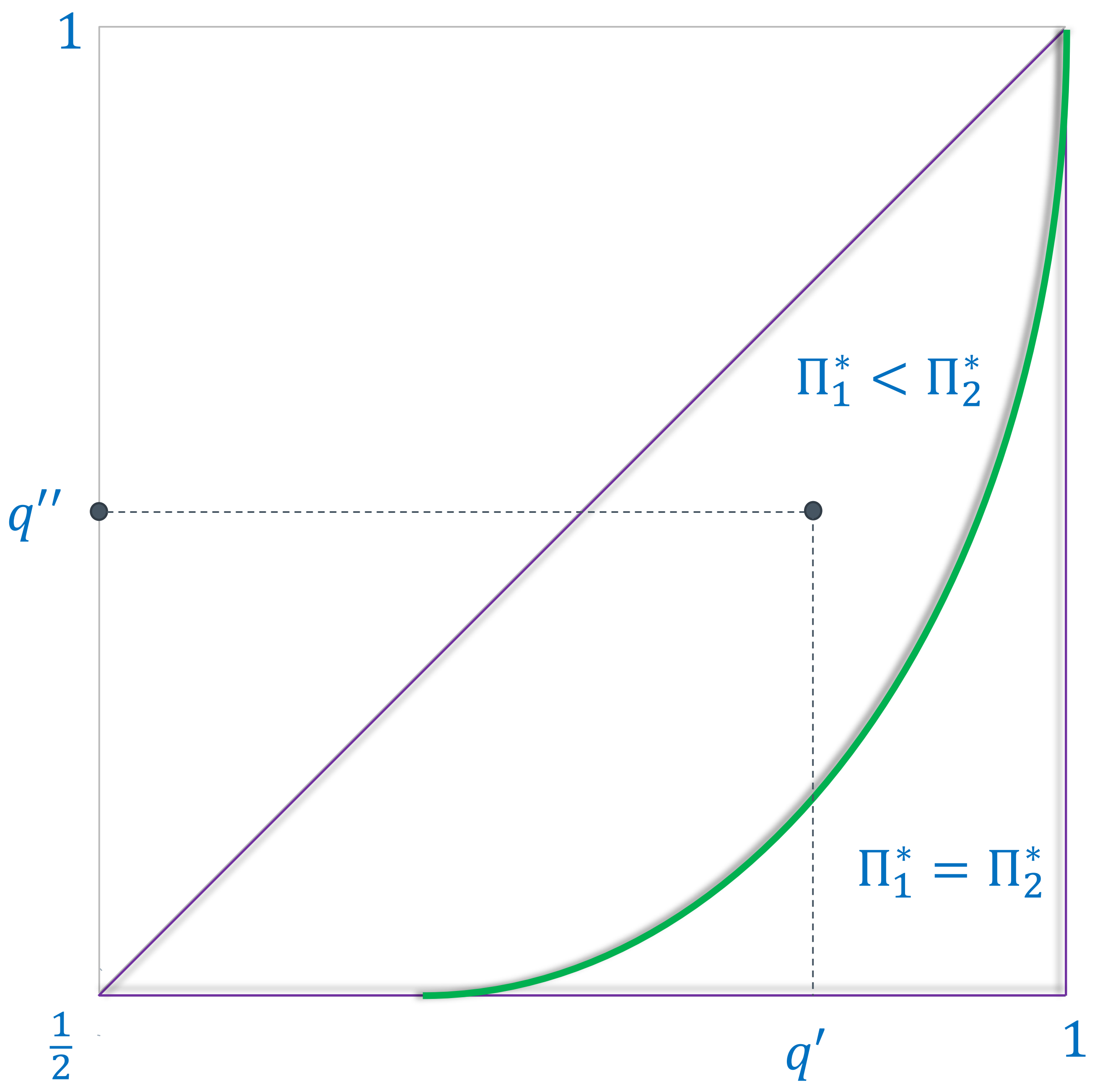

Π_i
Π_2^*
Π_1^*
$\frac{1}{2}$
q_2
q_1
1



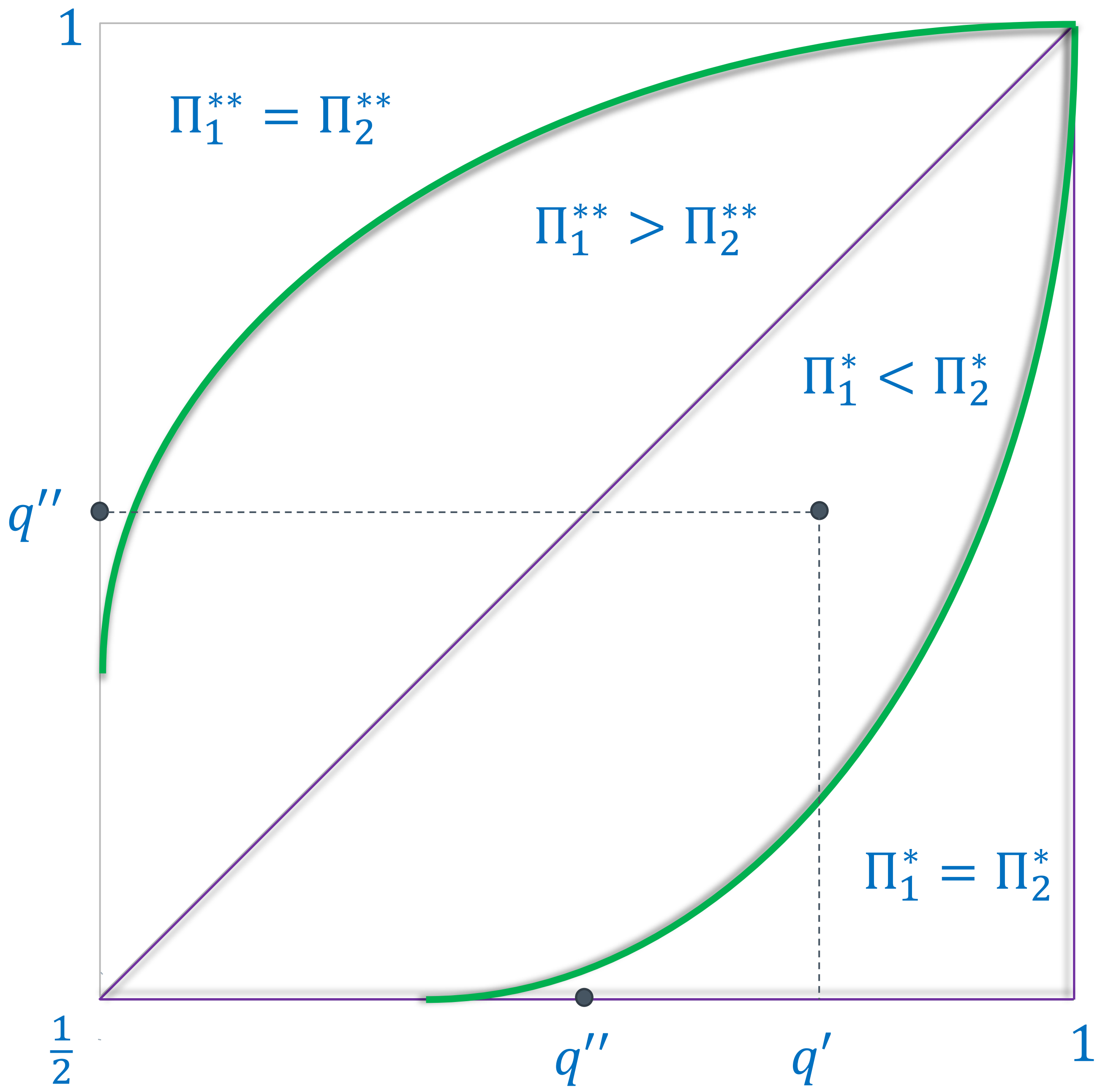
Π_i
$p(b_1, g_2) = p^*$
$p(b_1) = p^*$
Π_2^*
Π_1^*
$\frac{1}{2}$
q_2
q_1
1

Willful ignorance

- Suppose $\Pi_1^*(q', q'') < \Pi_2^*(q', q'')$.
- Can firm 1 gain by becoming completely uninformed?
- No, because $\Pi_1^*\left(\frac{1}{2}, q''\right) < \Pi_1^*(q', q'')$



1
$\Pi_1^* < \Pi_2^*$
q''
$\Pi_1^* = \Pi_2^*$
$\frac{1}{2}$
q'
1


1
$\Pi_1^{**} = \Pi_2^{**}$
$\Pi_1^{**} > \Pi_2^{**}$
$\Pi_1^{*} < \Pi_2^{*}$
q''
$\Pi_1^{*} = \Pi_2^{*}$
$\frac{1}{2}$
q''
q'
1

Why?

- Known reasons
  - ~~Second mover advantage~~
  - ~~Negative value of information~~

Why?

- Known reasons
  - ~~Second mover advantage~~
  - ~~Negative value of information~~

- New phenomenon
  - Knowledge prevents learning

Patent race with unobserved exit

- Two firms
  - Firm 1 (incumbent)
  - Firm 2 (startup)
- Continuous time, interest rate r
- R&D—flow cost c
- First success—flow profits m forever
- Irrevocable exit, unobserved

Patent race with unobserved exit

- Now learning rival's signal is not possible
- Strategy $\tau_i(s_i) \in \mathbb{R}_+ \cup \{\infty\}$
- Beliefs $p_t(s_i)$ decline monotonically
  - No jumps up because of good news

Patent race with unobserved exit

Proposition: With unobserved exit, there is a unique Nash equilibrium in which the better-informed firm 1 has a higher payoff than the less-informed firm 2.

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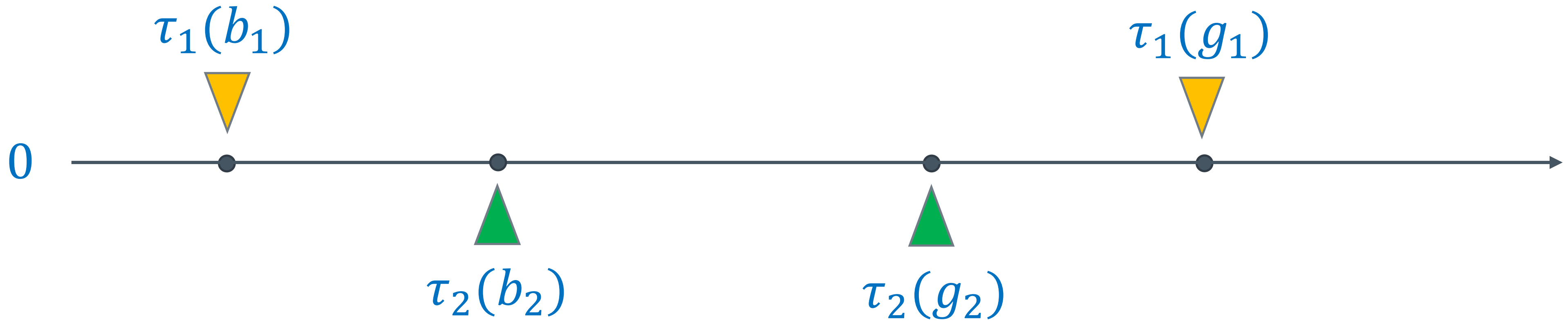
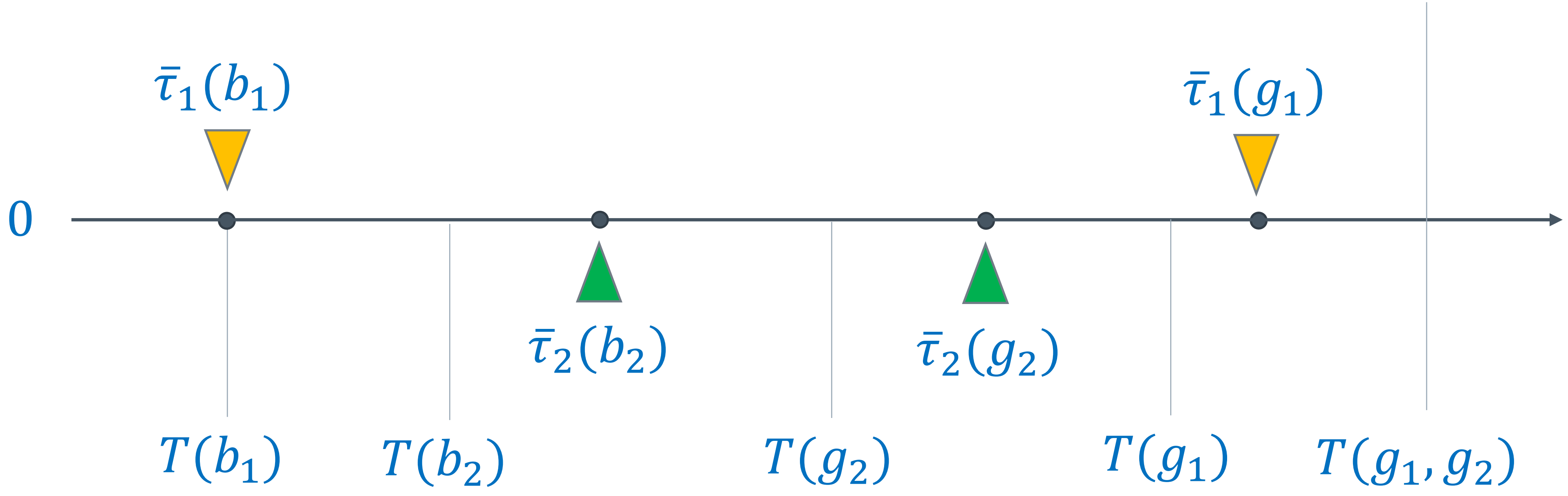
Equilibrium configuration



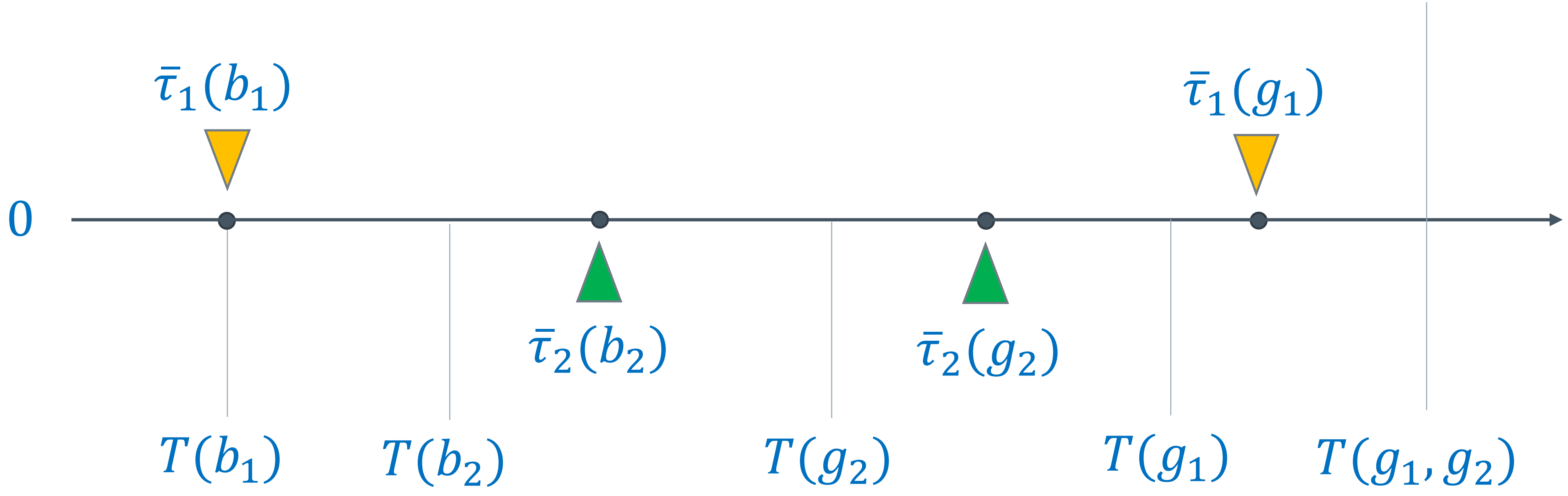
Equilibrium with unobserved exit

- $\bar{\tau}_1(b_1) = T(b_1)$
- $\bar{\tau}_2(b_2)$ solves $\frac{p(b_2)}{1-p(b_2)} e^{-\lambda t}\left((1-q_1)e^{-\lambda T(b_1)} + q_1 e^{-\lambda t}\right) = \frac{p^*}{1-p^*}$
- $\bar{\tau}_2(g_2)$ solves $\frac{p(g_2)}{1-p(g_2)} e^{-\lambda t}\left((1-q_1)e^{-\lambda T(b_1)} + q_1 e^{-\lambda t}\right) = \frac{p^*}{1-p^*}$
- $\bar{\tau}_1(g_1)$ solves
- $\frac{p(g_1)}{1-p(g_1)} e^{-\lambda t}\left((1-q_2)e^{-\lambda \bar{\tau}_2(b_2)} + q_2 e^{-\lambda \bar{\tau}_2(g_2)}\right) = \frac{p^*}{1-p^*}$

Equilibrium with unobserved exit



Equilibrium with unobserved exit



Roughly, firm 1's decisions are more responsive to information and so it gets a higher payoff.

Patent race with unobserved exit

Proposition: With unobserved exit, the overall probability of success is higher than if exit is observed.

Monitoring is socially harmful

Summary

In a game in which the only asymmetry is informational

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› there is a unique equilibrium

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In a game in which the only asymmetry is informational

- there is a unique equilibrium in which
- information is a competitive disadvantage
- even though it has positive value

- How? Better informed player has less incentive to learn

"In the delusions of entrepreneurs are the seeds of technological progress."

Surowiecki (2014)