Chapter 13 (§13C,D): Signaling, and Screening in Mas-Colell et al.
Chapter 16: Limit pricing in Tadelis

- Signaling (§13.C in MWG)
- Screening (§13.D in MWG)
- Limit pricing (§16.2 in Tadelis)
  A slightly generalized version based on Belleflamme and Peitz (2010)

§13.C Signaling

Basic assumptions

1. High type workers obtain degrees with low costs.
2. Low type workers obtain degrees with high costs.
3. Education has no effect on workers' productivity.

$\Theta = \{\theta_H, \theta_L\}$, $\theta_H > \theta_L > 0$, $\lambda = \Pr(\theta = \theta_H) \in (0, 1)$.

e: education level, $C(e, \theta)$: type θ's cost to obtain e.

Signaling game

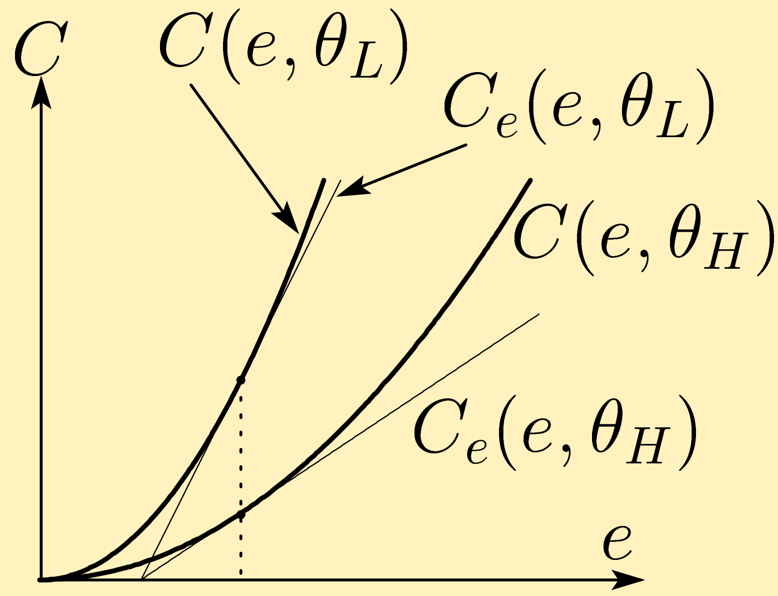
Basic assumptions (cont.)

$\forall\theta$, $C(0,\theta) = 0$.

$\forall\theta$, $\forall e$, $C_e(e,\theta) > 0$.

$\forall\theta$, $\forall e$, $C_{ee}(e,\theta) > 0$.

$\forall e$, $C(e,\theta_H) < C(e,\theta_L)$.



$\forall e$, $C_e(e,\theta_H) < C_e(e,\theta_L)$: single-crossing property.

Reservation payoff: $r(\theta_H) = r(\theta_L) = 0$.

Workers' payoff: $u(w, e|\theta) = w - C(e,\theta)$.

$\mu(e)$: The firm's belief that a worker is of type θ_H after it observes e.

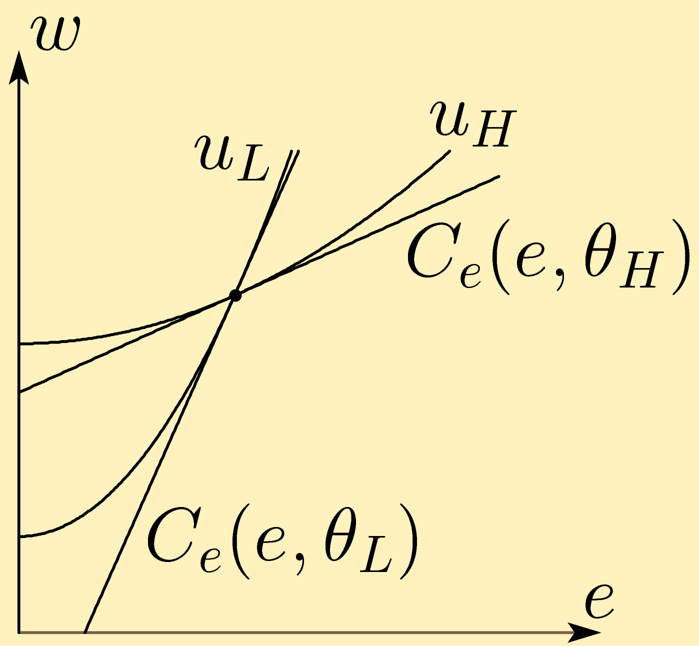
Signaling game

Single-crossing property (SCP) The indifference curves of the two types cross at most once.

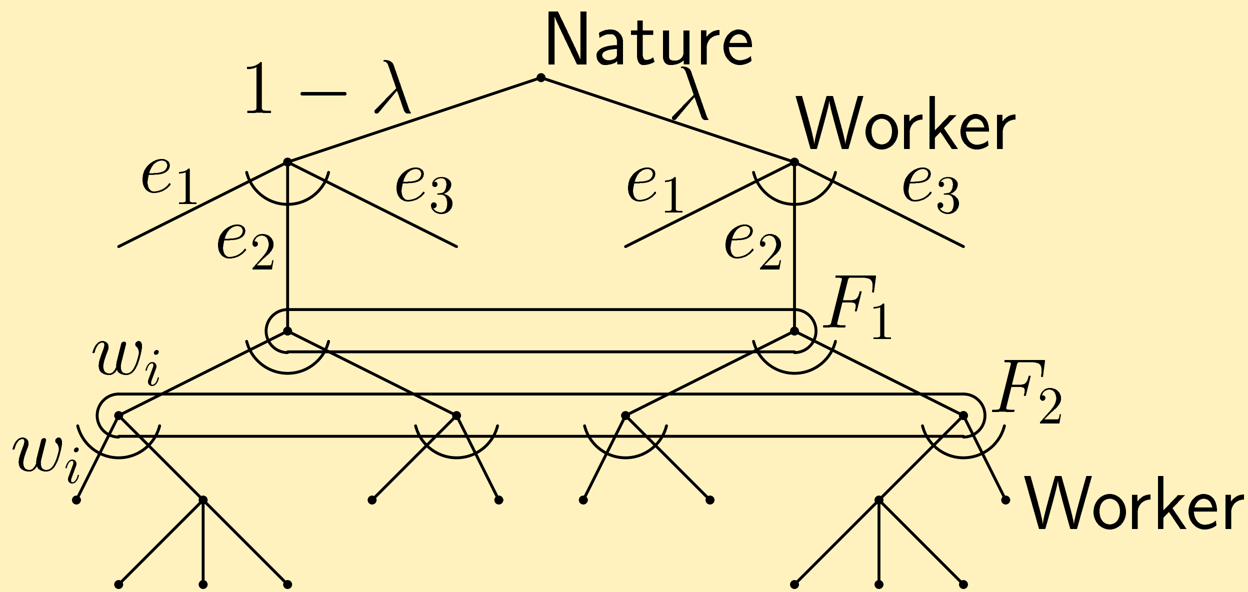
Indifference curve: $w = \bar{u} + C(e, \theta)$.

MRS: $\left.\dfrac{dw}{de}\right|_{u:const.} = C_e(e, \theta)$.

∂MRS$/\partial\theta = C_{e\theta}(e, \theta) < 0$.



The timing structure of the game



1. Nature determines the worker's ability, θ_H or θ_L.
2. Observing the ability, the worker determines e.
3. Observing e, each firm simultaneously offers w_i.
4. Observing the wages, the worker decides whether to work for a firm, if so, which one.

Signaling game

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1. The worker's strategy is optimal given the firms' strategies.
2. $\mu(e)$ is derived from the worker's strategy using Bayes' rule where possible.
3. The firms' wage offers $(w_1(e), w_2(e))$ following each e constitute a Nash equilibrium of the simultaneous move wage offer game in which the probability that the worker is of θ_H is $\mu(e)$.

Signaling game

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2. $\mu(e_H) = \lambda/\lambda = 1$ if $e_H \neq e_L$, and $\mu(e_H) = \lambda$ if $e_H = e_L$.
3. Given e, the firms' wage offers are those of the standard Bertrand model, so that $w_1(e) = w_2(e) = E(\theta; e) = \mu(e)\theta_H + (1 - \mu(e))\theta_L$.

   (3) The firms' wage offers $(w_1(e), w_2(e))$ following each e constitute a Nash equilibrium of the simultaneous move wage offer game in which the probability that the worker is of θ_H is $\mu(e)$.

Equilibria

Two types of equilibria

1. Separating: $e^*(\theta_H) \neq e^*(\theta_L)$.
2. Pooling: $e^*(\theta_H) = e^*(\theta_L)$.

$e^*(\theta)$ denotes an education choice function in a PBE.
$w^*(e)$ denotes a wage offer function in a PBE.

Separating equilibria

Lemma 13.C.1 In any separating PBE,

$$w^*(e^*(\theta_H)) = \theta_H \text{ and } w^*(e^*(\theta_L)) = \theta_L.$$

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Then,
$w^*(e^*(\theta_H)) = E(\theta|e^*(\theta_H)) = \theta_H$ and
$w^*(e^*(\theta_L)) = E(\theta|e^*(\theta_L)) = \theta_L$.

Lemma 13.C.2 In any separating PBE, $e^*(\theta_L) = 0$.

Proof: By contradiction. Suppose that $e^*(\theta_L) > 0$.

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From Lemma 13.C.1, type θ_L gains $\theta_L - C(e^*(\theta_L), \theta_L)$.

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Proof: By contradiction. Suppose that $e^*(\theta_L) > 0$.

From Lemma 13.C.1, type θ_L gains $\theta_L - C(e^*(\theta_L), \theta_L)$.

Choosing $e^*(\theta_L) = 0$ improves his/her gain.

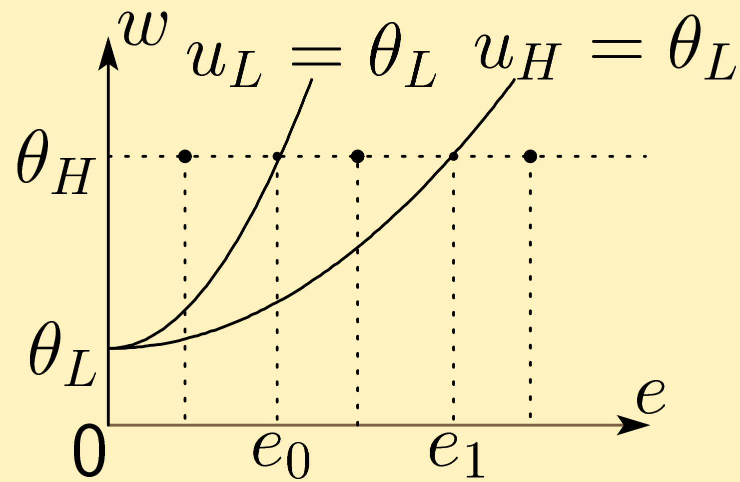
Separating equilibrium

Effort levels Let e_0 and e_1 be such that

$$\theta_L = \theta_H - C(e_0, \theta_L),$$
$$\theta_L = \theta_H - C(e_1, \theta_H).$$

Assume that

$e_H^* = e^*(\theta_H)$, $e_L^* = e^*(\theta_L)$ in PBE.



Fact 13.C.1 In any separating PBE, $e_0 \leq e_H^* \leq e_1$.

Separating equilibrium

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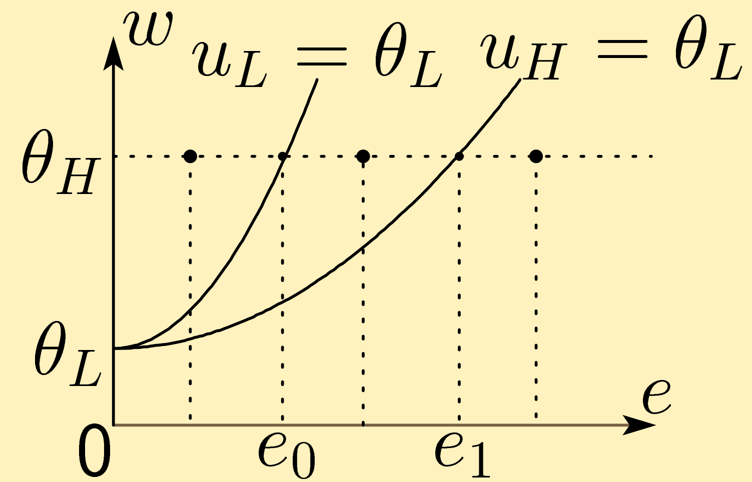

Fact 13.C.1 In any separating PBE, $e_0 \leq e_H^* \leq e_1$.

By Lemmas 1 and 2, $w(e_L^*) = \theta_L$, $w(e_H^*) = \theta_H$, $e_L^* = 0$.

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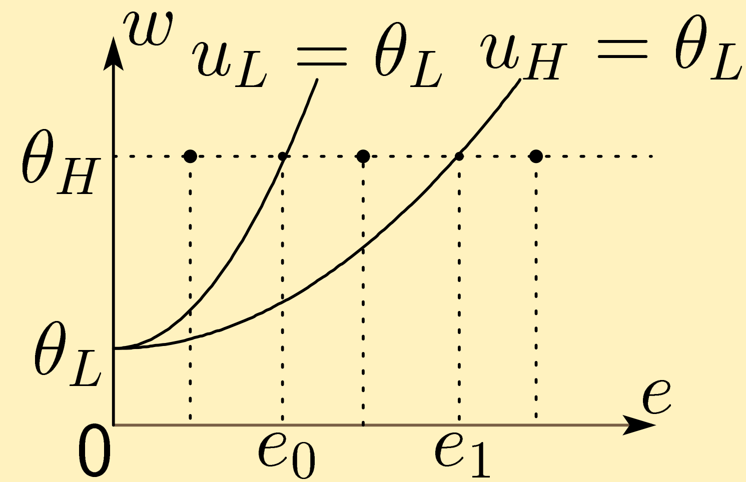

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If $e_H^* < e_0$, $\theta_L < u_L = \theta_H - C(e_H^*, \theta_L)$. Type θ_L can be better off by choosing e_H^*.

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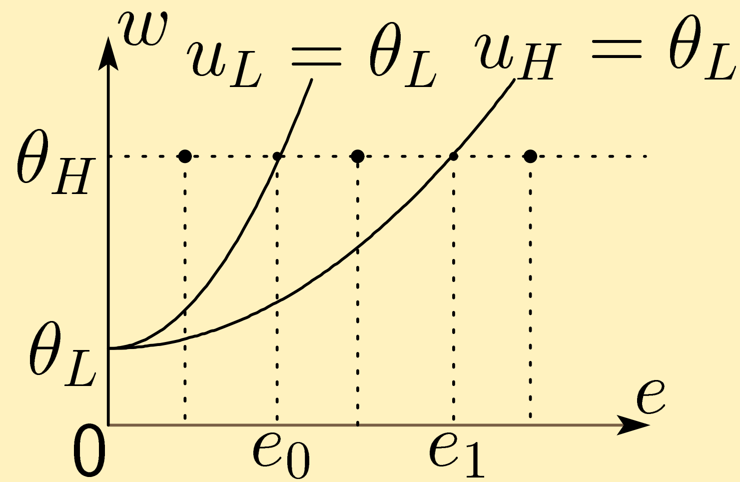

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If $e_H^* > e_1$, $\theta_L > u_H = \theta_H - C(e_H^*, \theta_H)$. Type θ_H can be better off by choosing e_L^*.

Separating equilibrium

Fact 13.C.2 In any PBE, μ^* is such that for all $\theta \in \Theta$,

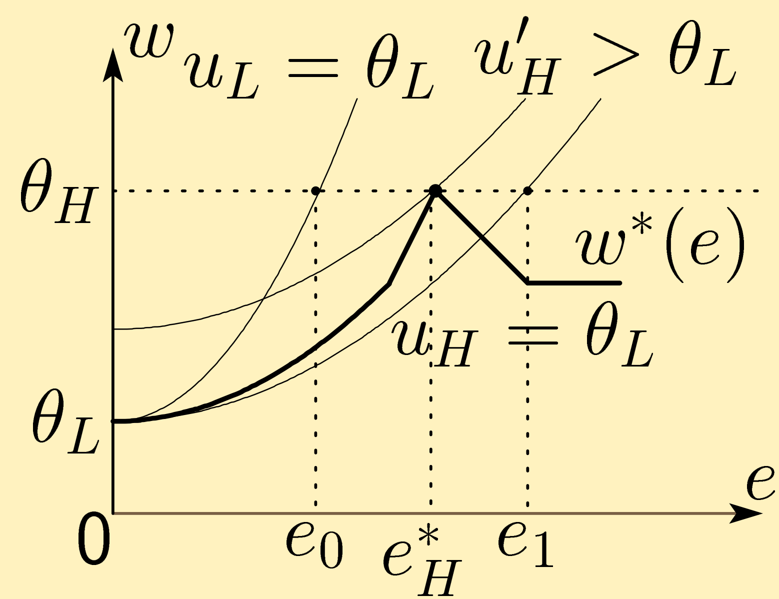
$$
\begin{aligned}
e^*(\theta) &= \arg\max_e \{w^*(e) - C(e,\theta)\} \\
&= \arg\max_e \{[\mu^*(e)\theta_H + (1-\mu^*(e))\theta_L] - C(e,\theta)\}.
\end{aligned}
$$

Separating equilibrium

Fact 13.C.2 In any PBE, μ^* is such that for all $\theta \in \Theta$,

$$e^*(\theta) = \arg\max_e \{w^*(e) - C(e,\theta)\}$$
$$= \arg\max_e \{[\mu^*(e)\theta_H + (1-\mu^*(e))\theta_L] - C(e,\theta)\}.$$

Fact 13.C.3 The strategies and beliefs described in Remark, Lemmas 13.C.1 and 2, and Facts 13.C.1 and 2 constitute a separating PBE.



Separating equilibrium

Ex. 1 $\theta_L = 1$, $\theta_H = 2$, $C(e, \theta_L) = e^2$, $C(e, \theta_H) = e^2/4$.

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$$\theta_L = \theta_H - C(e_0, \theta_L) \;\rightarrow\; e_0 = 1,$$
$$\theta_L = \theta_H - C(e_1, \theta_H) \;\rightarrow\; e_1 = 2.$$

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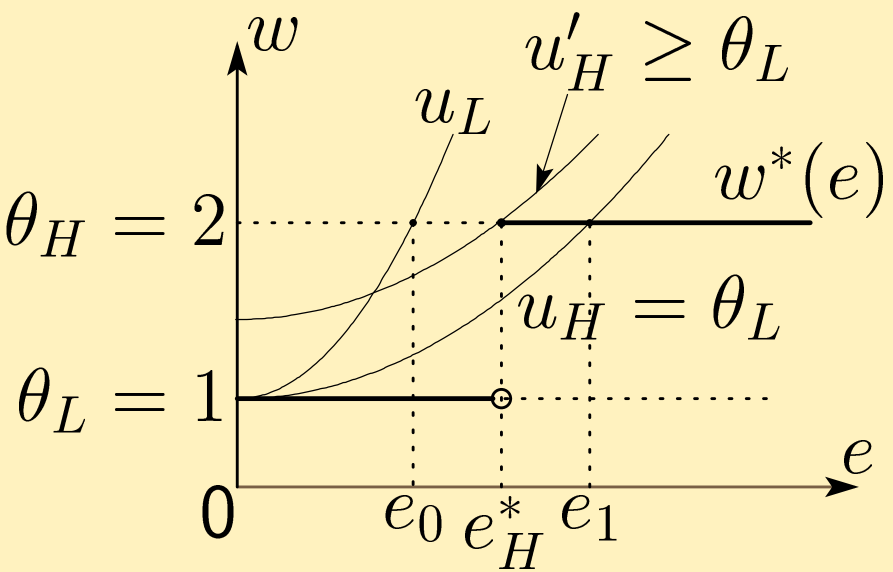
Let $e_H^* \in [1,2]$, and let μ^* and $w^*(\cdot)$ be such that

$$\mu^*(e) = \begin{cases} 1 & \text{if } e \geq e_H^*, \\ 0 & \text{if } e < e_H^*. \end{cases}$$

$$w^*(e) = \begin{cases} \theta_H & \text{if } e \geq e_H^*, \\ \theta_L & \text{if } e < e_H^*. \end{cases}$$



Separating equilibrium

Fact 13.C.4 In any separating PBE, the profits of the firms are zero, type L worker obtains θ_L, type H worker obtains $\theta_H - C(e^*(\theta_H), \theta_H)$.

Separating equilibrium

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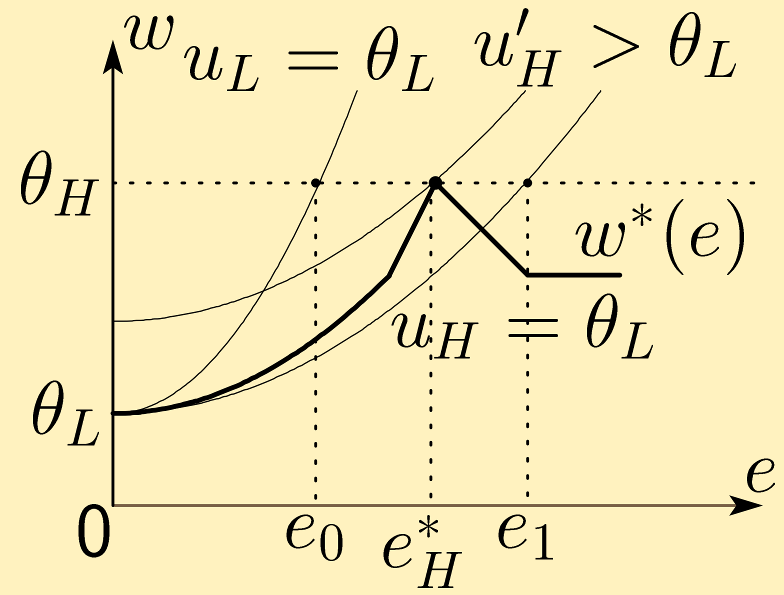
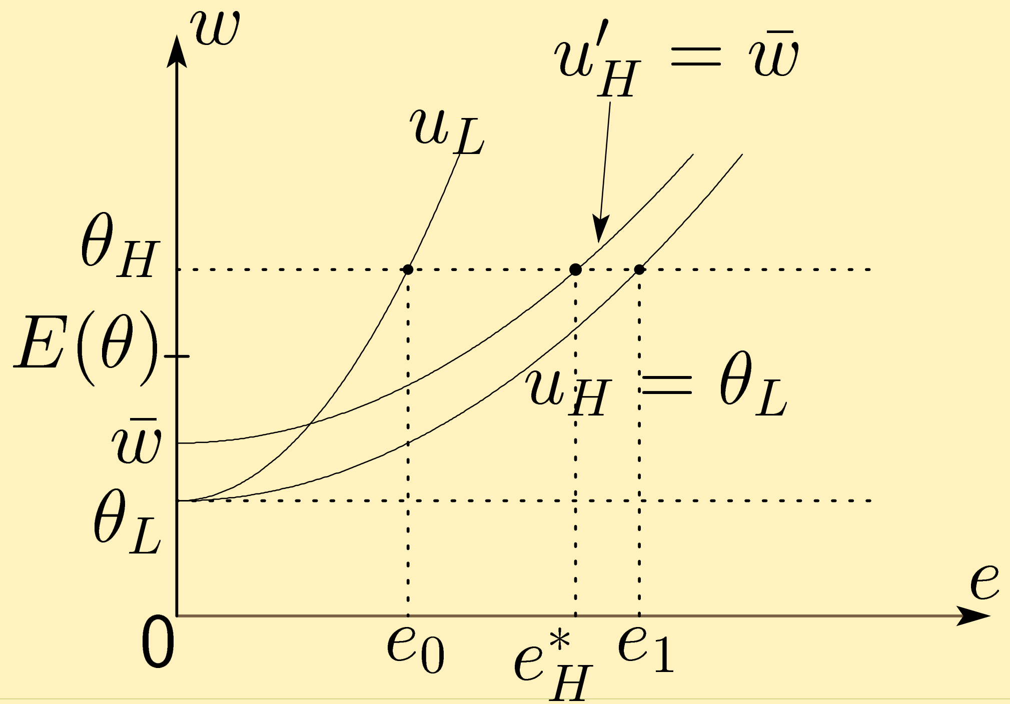
Fact 13.C.5 The separating PBE with $e^*(\theta_H) = e_0$ Pareto-dominates any other separating equilibria.



Separating equilibrium

Fact 13.C.6 Consider a separating PBE with $e^*(\theta_H) = e^*_H$. Let $\bar{w} = \theta_H - C(e^*_H, \theta_H)$, and let α be such that $\alpha\theta_H + (1-\alpha)\theta_L = \bar{w}$.

If $\alpha < \lambda$, the allocation without signals Pareto-dominates the separating PBE.



Pooling equilibrium

Pooling $e^* = e^*(\theta_L) = e^*(\theta_H)$ in a pooling PBE.

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Fact 13.C.7 In any pooling PBE,

$$w^*(e^*) = E(\theta) = \lambda\theta_H + (1-\lambda)\theta_L.$$

Pooling equilibrium

Pooling $e^* = e^*(\theta_L) = e^*(\theta_H)$ in a pooling PBE.

Fact 13.C.7 In any pooling PBE,

$$w^*(e^*) = E(\theta) = \lambda\theta_H + (1-\lambda)\theta_L.$$

Fact 13.C.8 In any pooling PBE with $e^* = e^*(\theta_L)$,

the profits of the firms are zero,

type L worker obtains $E(\theta) - C(e^*, \theta_L)$,

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Pooling equilibrium

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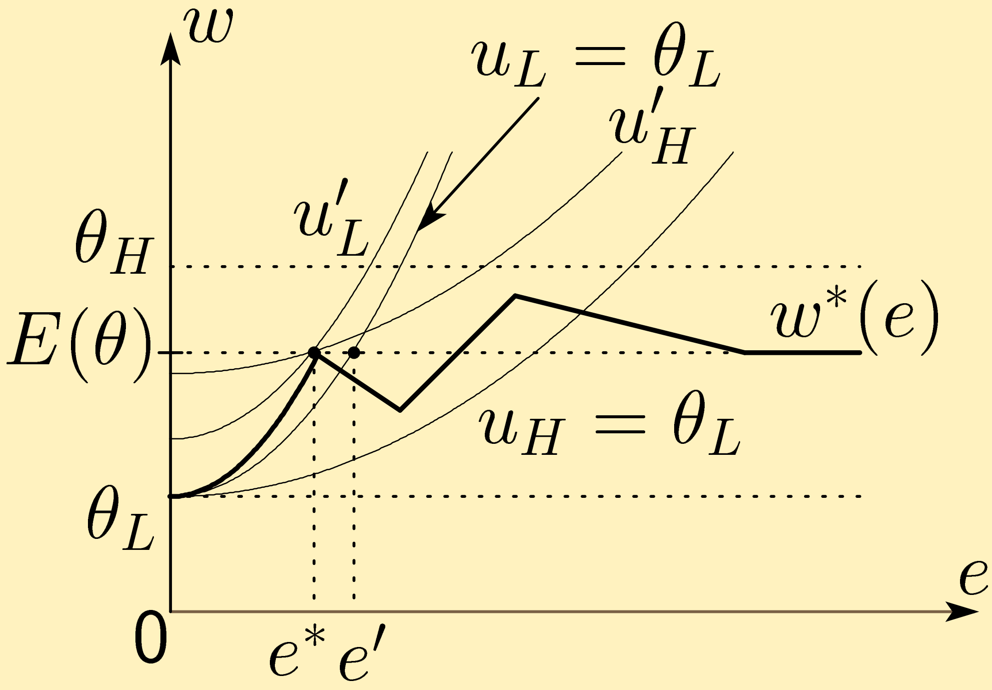
Fact 13.C.9 In any pooling PBE with $e^* = e^*(\theta_L)$,

$0 \le e^* \le e'$ where e' satisfies $E(\theta) - C(e', \theta_L) = \theta_L$.

Proof: If $e > e'$, then type L chooses $e = 0$ because he/she gains at least θ_L.

Pooling equilibrium

Fact 13.C.10 The strategies and beliefs described in Remark of def. of PBE, Facts 13.C.2, 7, and 9 constitute a pooling PBE.



Pooling equilibrium

Ex. 2 $\theta_L = 1$, $\theta_H = 2$, $C(e, \theta_L) = e^2$, $C(e, \theta_H) = e^2/4$, $\lambda = 1/2$.

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$E(\theta) = 1 \times (1/2) + 2 \times (1/2) = 3/2.$

$\theta_L = E(\theta) - C(e', \theta_L) \ \rightarrow \ e' = \sqrt{2}/2.$

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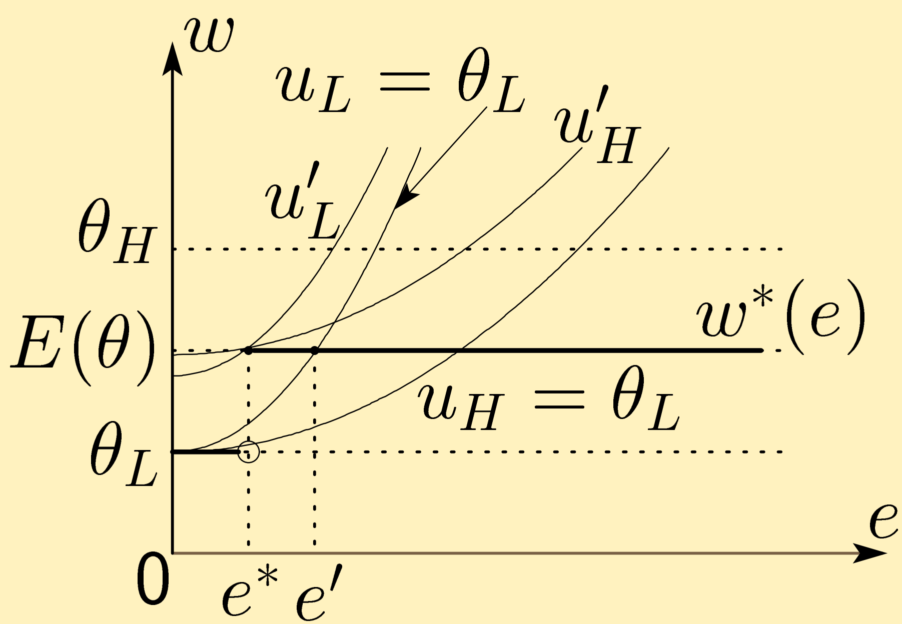
Let $e^* \in [0, \sqrt{2}/2]$. Let μ^* and w^* be such that

$$\mu^*(e) = \begin{cases} \lambda & \text{if } e \geq e^*, \\ 0 & \text{if } e < e^*. \end{cases}$$

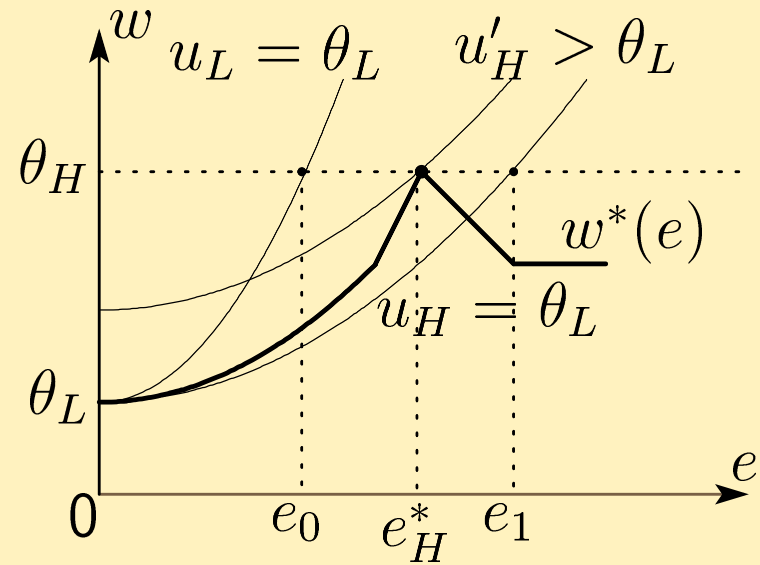
$$w^*(e) = \begin{cases} E(\theta) & \text{if } e \geq e^*, \\ \theta_L & \text{if } e < e^*. \end{cases}$$



Multiple equilibria and equilibrium refinement

Intuitive criterion (Cho and Kreps (1987)).

Consider a separating PBE in the figure. If type L chooses $e' \in (e_0, e^H)$, he/she will be worse off than choosing $e = 0$, regardless of the belief.



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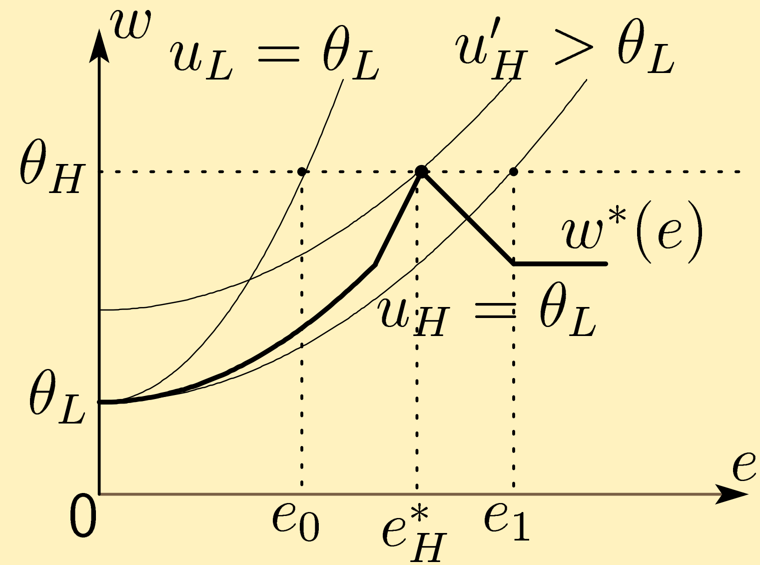

Type L will never choose $e > e_0$.

For $e \in (e_0, e_1)$, $\mu(e) \in [0, 1)$ is not reasonable.

So, $\mu(e) = 1$ for all $e \in (e_0, e_1)$.

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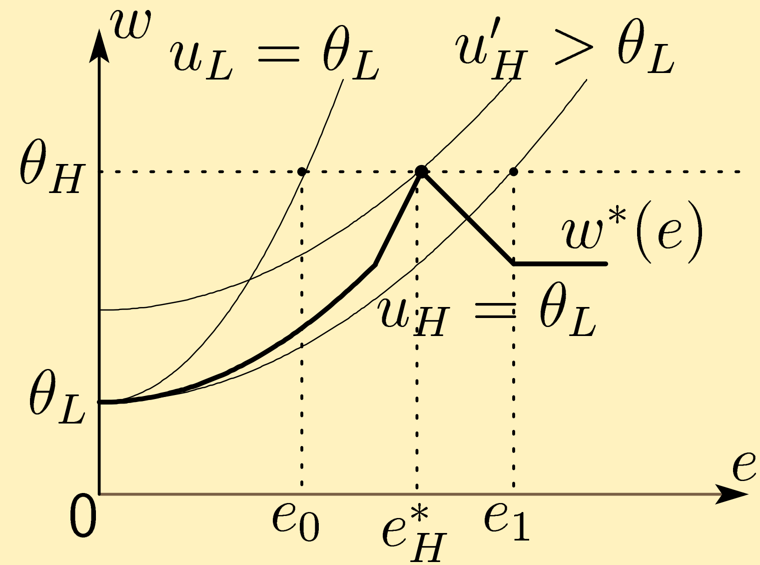

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Type H will be better of by choosing $e' \in (e_0, e^*_H)$.

Any separating PBE with $e^*_H > e_0$ is not sustained.

§13.D Screening

Basic assumptions As in Section 13.C,

1. Two types of workers θ_L and θ_H ($\theta_H > \theta_L > 0$), where $\lambda = \Pr(\theta = \theta_H) \in (0, 1)$.
2. The reservation wage of each worker is zero ($r(\theta_H) = r(\theta_L) = 0$).
3. Jobs might differ in the "task level" required of the worker.

   To simplify the analysis, assume that higher task levels add nothing to the output of the worker.

   The output of a type θ is θ regardless of the task.

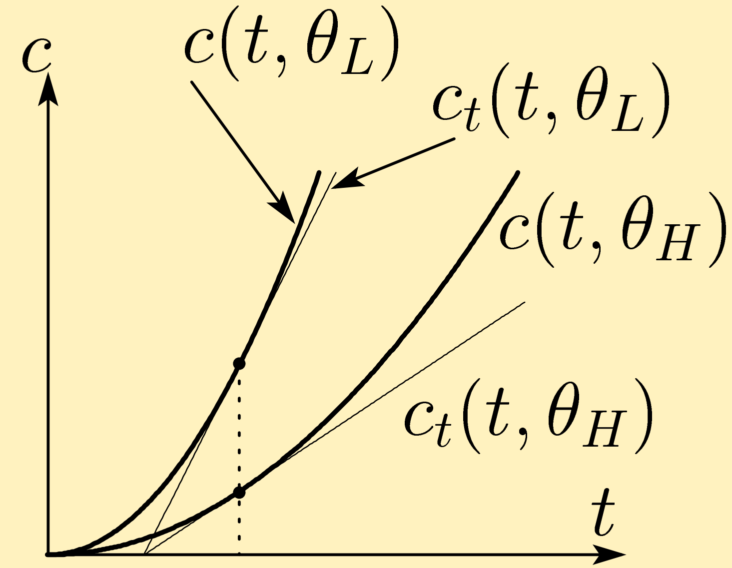
Basic assumptions (cont.)

$\forall\theta$, $c(0,\theta) = 0$.

$\forall\theta$, $\forall t$, $c_t(e,\theta) > 0$.

$\forall\theta$, $\forall t$, $c_{tt}(e,\theta) > 0$.

$\forall t$, $c(e,\theta_H) < c(e,\theta_L)$.



$\forall t$, $c_t(e,\theta_H) < c_t(t,\theta_L)$: single-crossing property.

Workers' payoff: $u(w,t|\theta) = w - c(t,\theta)$.

Screening

Timing We consider the following two stage game.

1. Two firms simultaneously announce sets of offered contracts. A contract is a pair (w, t).
2. Given the offers, each type worker chooses whether to accept a contract and, if so, which one.

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Proposition 13.D.1 In any SPNE of the screening game with **observable** worker types (complete information case),

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Proposition 13.D.1 In any SPNE of the screening game with **observable** worker types (complete information case), a type θ_i worker accepts contract $(w_i^*, t_i^*) = (\theta_i, 0)$, and firms earn zero profits.

Intuition: Bertrand competition between the firms.

Screening

Incomplete information Types are *not observable*.

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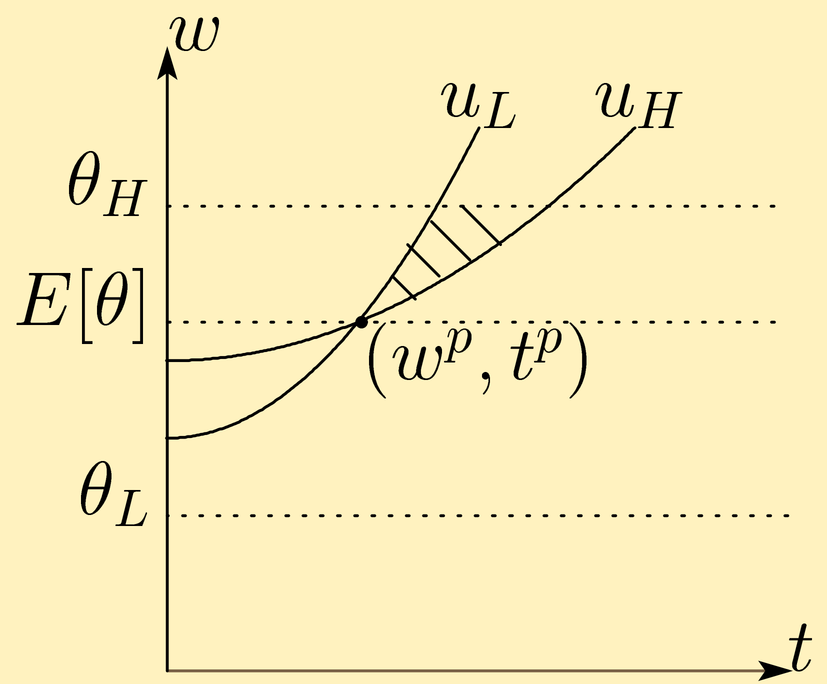
Lemma 13.D.2 No pooling equilibria exist.

Proof By contradiction. (w^p, t^p) is a pooling equilibrium contract. By Lemma 13.D.1, (w^p, t^p) lies on the break-even line (see Figure). Given the contract, a firm earns a positive profit by offering a contract on the shaded area.



(w_j, t_j): a contract signed by j workers ($j = H, L$).

Lemma 13.D.3 In a separating equilibrium, the contracts (w_H, t_H) and (w_L, t_L) yield zero profits. That is, $w_H = \theta_H$ and $w_L = \theta_L$.

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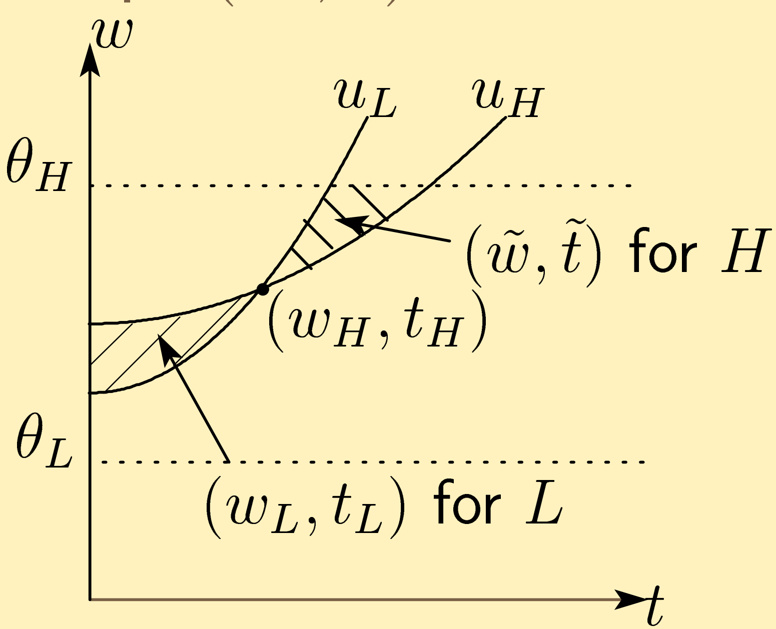
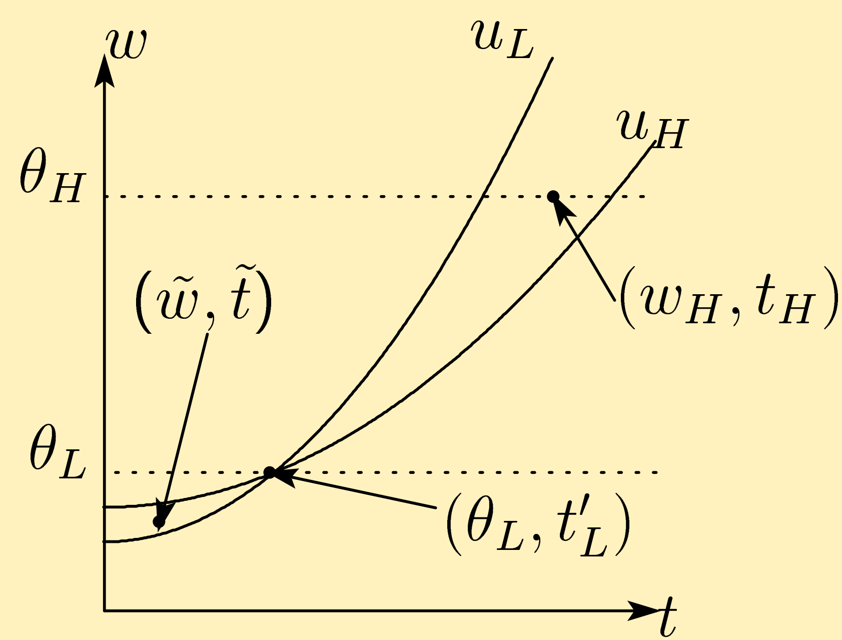
Lemma 13.D.4 In any separating equilibrium, L workers accept $(\theta_L, 0)$.





Lemma 13.D.5 In any separating equilibrium, H workers accept $(\theta_H, \hat{t}_H)$ such that

$$\theta_H - c(\hat{t}_H, \theta_L) = \theta_L - c(0, \theta_L).$$

Screening

Lemma 13.D.5 In any separating equilibrium, H workers accept $(\theta_H, \hat{t}_H)$ such that

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Intuition behind the lemma By Lemmas 13.D.3 and 13.D.4, $(w_L, t_L) = (\theta_L, 0)$ and $w_H = \theta_H$.

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t_H must be at least as large as $\hat{t}_H$ (no mimic).

Screening

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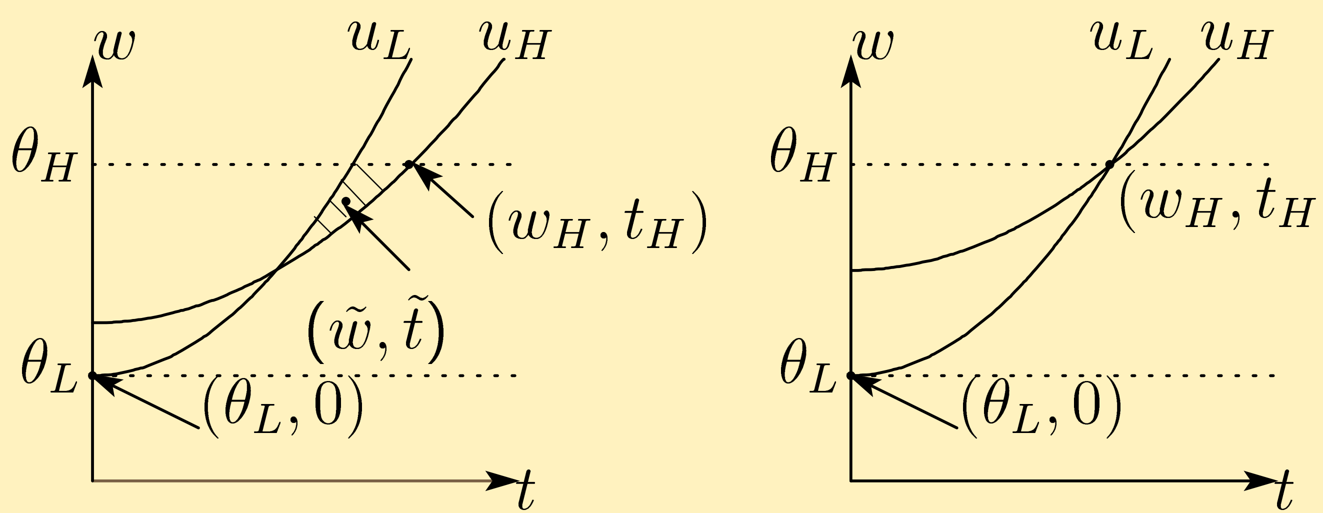
Intuition behind the lemma By Lemmas 13.D.3 and 13.D.4, $(w_L, t_L) = (\theta_L, 0)$ and $w_H = \theta_H$.

If $t_H > \hat{t}_H$, a firm can offer a more favorable contract for H workers.



Screening

Proposition 13.D.2 In any SPNE of the screening game, L workers accept $(\theta_L, 0)$, and H workers accept $(\theta_H, \hat{t}_H)$ such that $\theta_H - c(\hat{t}_H, \theta_L) = \theta_L - c(0, \theta_L)$.

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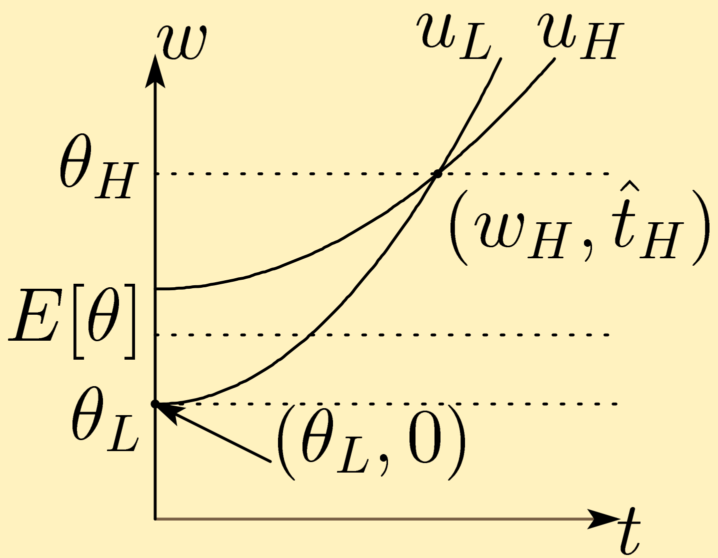
Remark This equilibrium is not always sustainable.



No pooling

Screening

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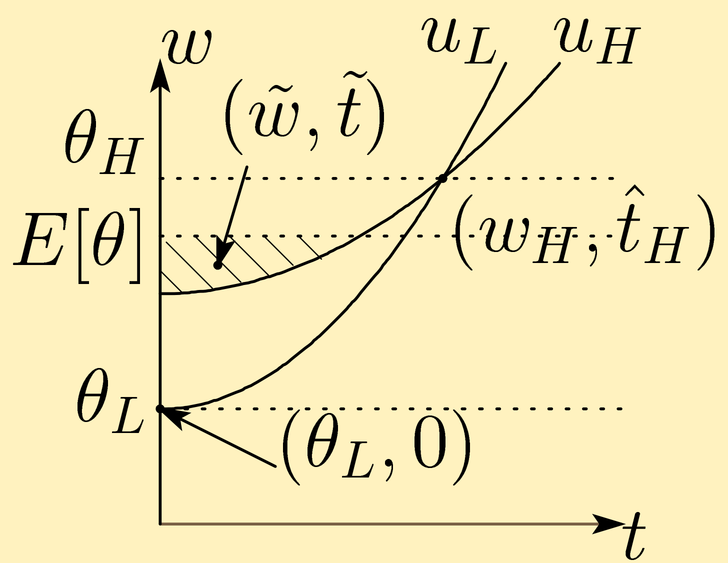

Deviation 1

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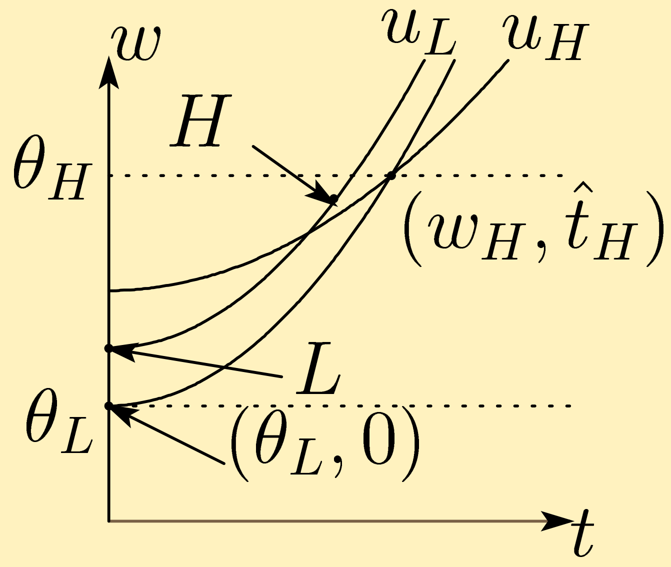

Deviation 2

Limit pricing

Limit pricing One incumbent and one potential entrant exist. The incumbent can set a low price in order to avoid or delay entry.

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The setting Two-period Cournot comp. with $P(Q) = 1 - Q$.

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$t = 0$ The cost of firm 1 is realized.
$c = c_H$ with probability μ or
$c = c_L = 0$ with probability $1 - \mu$ $(c_L < c_H < 1/2)$.

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whether to enter and pay the fixed cost e.
$\varepsilon = 1$ means entry and $\varepsilon = 0$ means no entry.

The entry strategy is denoted by $\varepsilon(p_1(q_1))$.
After the entry, the entrant learns the incumbent's cost, and they compete in quantity at period 2.

Limit pricing

The setting $c = c_H$ with prob. μ or $c = c_L = 0$ with prob. $1-\mu$, $0 = c_L < c_H < 1/2$. The incumbent sets $q_1(c)$. The entry strategy is denoted by $\varepsilon(p_1(q_1))$.

The second stage If no entry occurs, the incumbent sets $q_{2I}(c; \varepsilon = 0) = (1-c)/2$ (the monopoly quantity when its marginal cost is c).

Limit pricing

The setting $c = c_H$ with prob. μ

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$q_{2I}(c; \varepsilon = 0) = (1 - c)/2$.

If the entry occurs, the firms set

$$q_{2I}(c_H; \varepsilon = 1) = (1 - 2c_H)/3, \ q_{2E}(c_H; \varepsilon = 1) = (1 + c_H)/3,$$

$$q_{2I}(c_L; \varepsilon = 1) = 1/3, \quad q_{2E}(c_L; \varepsilon = 1) = 1/3.$$

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Complete information If the entrant knows the true cost of the incumbent before its entry,

$$\pi_E(c_H; 1) = (1+c_H)^2/9, \quad \pi_E(c_L; 1) = 1/9.$$

We consider the case in which $\pi_E(c_L; 1) < e < \pi_E(c_H; 1)$.

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Pooling Eq. The entrant uses prior beliefs. Its expected profit is

$$\mu \pi_E(c_H; 1) + (1 - \mu)\pi_E(c_L; 1).$$

If e is larger than this expected profit, an uninformed entrant does not enter. The expected profit is smaller than $\pi_E(c_H; 1)$.

Limit pricing

The setting $\pi_E(c_L; 1) < e < \pi_E(c_H; 1)$.

Pooling Eq. An uninformed entrant does not enter iff

$$\mu\pi_E(c_H; 1) + (1 - \mu)\pi_E(c_L; 1) < e.$$

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The total profit of the incumbent with $c = c_H$ when it sets $q_1 = 1/2$ is $\pi_I(c_H;0) \equiv (1-2c_H)/4 + (1-c_H)^2/4$.

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The total profit of the incumbent with $c = c_H$ when it sets $q_1 = (1 - c_H)/2$ is $\pi_I(c_H; 1) \equiv (1 - c_H)^2/4 + (1 - 2c_H)^2/9$.

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The incumbent sets $q_1 = 1/2$ if $\pi_I(c_H;0) > \pi_I(c_H;1)$, that is,

$(1-2c_H)/4 + (1-c_H)^2/4 > (1-c_H)^2/4 + (1-2c_H)^2/9$.

For any c_H, the incumbent with $c = c_H$ sets $q_1 = 1/2$ that is the monopoly quantity of the incumbent with $c = 0$.