Information and strategic interaction

Assumptions of *perfect competition*:

(i) agents (believe they) cannot influence the market price
(ii) agents have all relevant information

What happens when neither (i) nor (ii) holds?

Strategic interaction among a group of firms where some or all are incompletely informed

In particular: What happens when a firm knows more than the others about demand, own costs, etc.?

Equilibrium outcome is now also determined by incompletely informed firms' beliefs. These beliefs are represented by subjective probabilities.

(i) Incomplete information in a static model
  - how beliefs determine the equilibrium

(ii) … in a dynamic model
  - how beliefs are formed

Games with incomplete information

Perfect Bayesian Equilibrium:
Both strategies and beliefs are in equilibrium.

- Given the strategies in equilibrium, which revised beliefs are consistent with these strategies?

- Given the beliefs in equilibrium, which strategies are in equilibrium?

Two different kinds of problem:
- Asymmetric information – and the importance of the uninformed firm observing the informed firm's actions.
- Symmetric, incomplete information – and how there still may be a lot of action even though firms cannot observe each other's actions.

Signalling

A typical signalling game:

Stage 1: The *informed* player chooses an action (*signals*)

Stage 2: The uninformed player observes stage 1, revises his beliefs about the informed player, and chooses an action himself.

The informed player's private information – his type

$$\theta \in \{\text{High, Low}\}$$

The uninformed player's beliefs about the other's type:

Initial beliefs

Pr(High) = p_H
Pr(Low) = $p_L = 1 - p_H$

Stage 2: *revised* beliefs

Equilibrium: actions and revised beliefs

Separating equilibrium: the action taken by the informed player at stage 1 depends on his type.

Pooling equilibrium: the action taken by the informed player at stage is independent of his type.

In a pooling equilibrium, the uninformed player learns nothing about the other player's type from observing his stage-1 action. Beliefs cannot be updated based on that action.

In a separating equilibrium, on the other hand, the stage-1 action reveals the informed player's type, and so, based on that action, the uninformed player can update his beliefs about the other player's type and act accordingly.

First – a static model:
<u>Price competition with asymmetric information</u>

Two firms. Product differentiation. Price competition.

Product differentiation: A slight increase in a firm's price causes a slight decrease in its demand and a slight increase in the other firm's demand.

$$D_1 = D_1(\underset{-}{p_1}, \underset{+}{p_2}); \quad D_2 = D_2(\underset{-}{p_2}, \underset{+}{p_1})$$

Firm 1 has private information about own costs.
Both firms know firm 2's costs.

Firm 1's unit costs:

$c_1 = c_1^L$, with probability x

$c_1 = c_1^H$, with probability $(1 - x)$

$c_1^L < c_1^H$

Firm 2 only knows the probability distribution (c_1^L, c_1^H, x)

Firm 1 knows both c_1 and the probability distribution.

In the case of *complete information*:

$\pi_1 = (p_1 - c_1)D_1(p_1, p_2)$

$$\frac{\partial \pi_1}{\partial p_1} = D_1(p_1, p_2) + (p_1 - c_1)\frac{\partial D_1(p_1, p_2)}{\partial p_1} = 0$$

Best response of firm 1: $R_1(p_2)$.

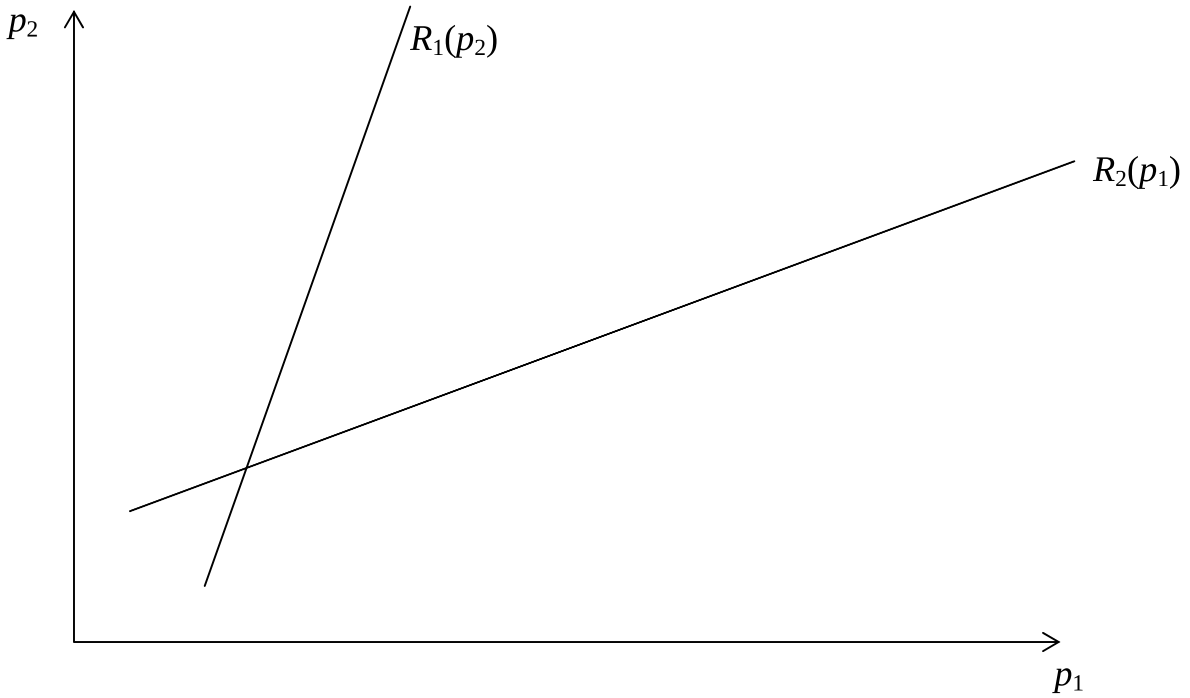
Slope of the best response:

$$\text{sign } R_1'(p_2) = \text{sign } \frac{\partial^2 \pi^1}{\partial p_1 \partial p_2}.$$

$$\frac{\partial^2 \pi_1}{\partial p_1 \partial p_2} = \frac{\partial D_1(p_1, p_2)}{\partial p_2} + (p_1 - c_1)\frac{\partial^2 D_1(p_1, p_2)}{\partial p_1 \partial p_2}$$

- First term positive
- Slope of the best response positive unless $\frac{\partial^2 D_1}{\partial p_1 \partial p_2}$ very negative.

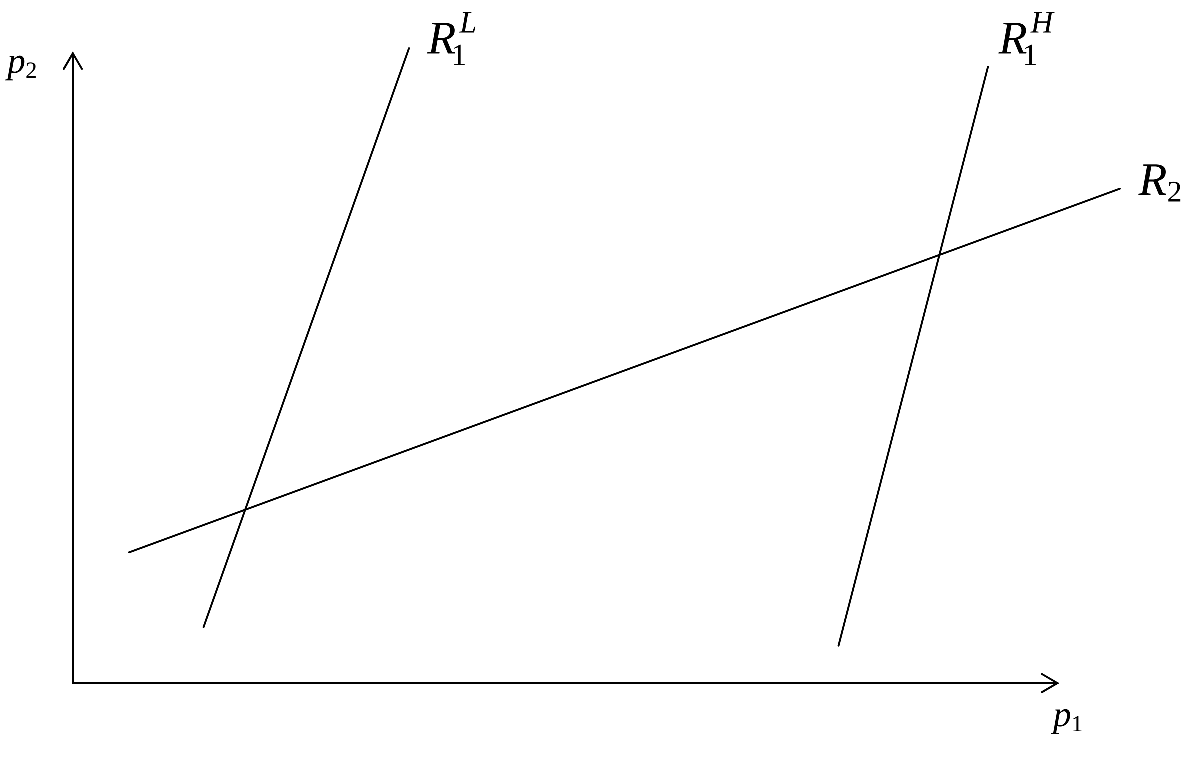
Equilibrium with complete information:



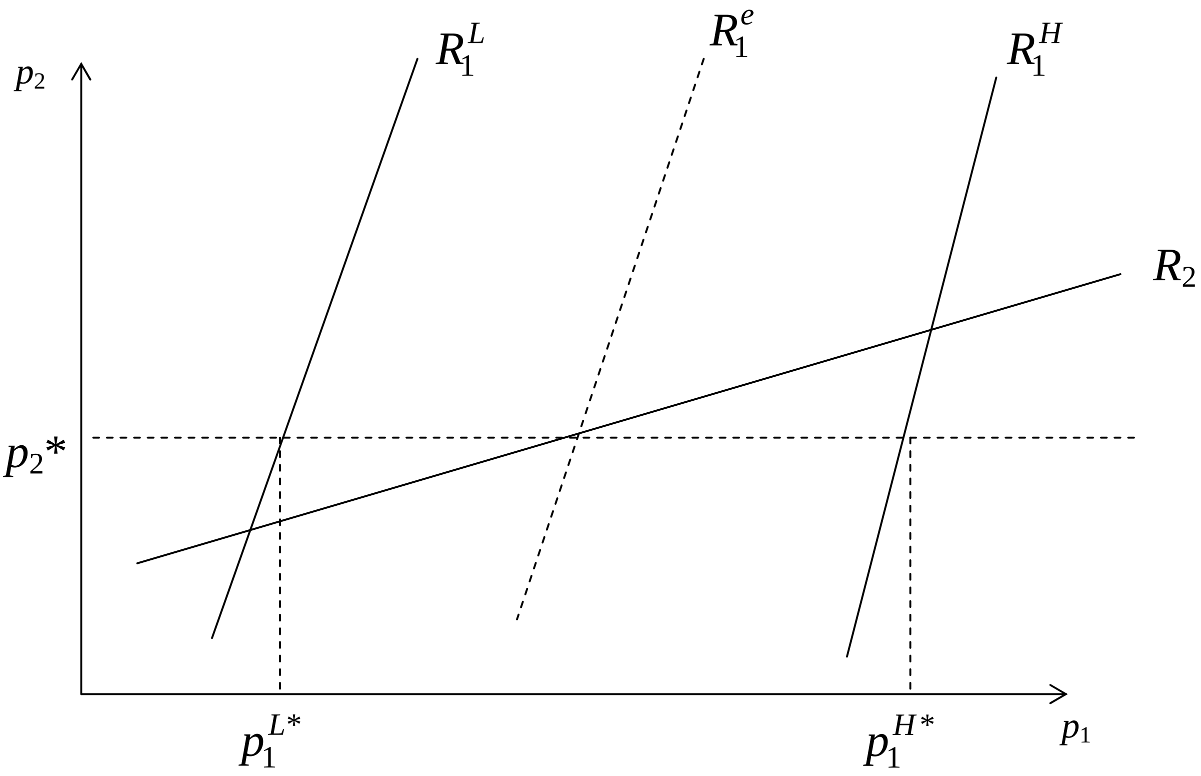
The optimum p_1 is increasing in c_1:

$$\frac{\partial^2 \pi_1}{\partial p_1^2} dp_1 + \frac{\partial^2 \pi_1}{\partial p_1 \partial c_1} dc_1 = 0$$

$$\frac{dp_1}{dc_1} = -\frac{\partial^2 \pi_1 / \partial p_1 \partial c_1}{\partial^2 \pi_1 / \partial p_1^2} = \frac{\partial D_1 / \partial p_1}{\partial^2 \pi_1 / \partial p_1^2} > 0$$



Firm 2 doesn't know firm 1's *type*. Firm 2 behaves as if confronting an *expected* firm 1.



Analytically, we find three prices:

The price of the uninformed firm.
The price of the informed firm if it has high costs.
The price of the informed firm if it has low costs.

How is the equilibrium affected by incomplete information?

If firm 1 is *low-cost*, then incomplete information *increases* the equilibrium prices.

If firm 1 is *high-cost*, then incomplete information *reduces* the equilibrium prices.

Probability of firm 1 being low-cost: x

An increase in x reduces equilibrium prices, whether firm 1 is low-cost or high-cost.

If firm 1 could choose x, it would want x to be low, whether the firm actually is low-cost or high-cost.

- The informed firm would like to be believed to have high costs, because that would keep prices high.

Dynamic model

Stage 1: An action by firm 1 that may potentially influence firm 2's subjective probability that firm 1 is low-cost.

Stage 2: Price competition with asymmetric information

What action?

(i) Verifying costs – external audit
Verification is good for firm 1 if it is high-cost, but not if it is low-cost.

(ii) Verification not possible

Model: Two-period price competition between two firms

Period 1: Price competition

Period 2: Price competition

Is it possible for firm 2 to infer firm 1's cost from firm 1's price in stage 1?

In period 1, a high-cost firm 1 would want to set a price that reveals its cost, while a low-cost firm 1 would not want to reveal its cost.

Signalling game.

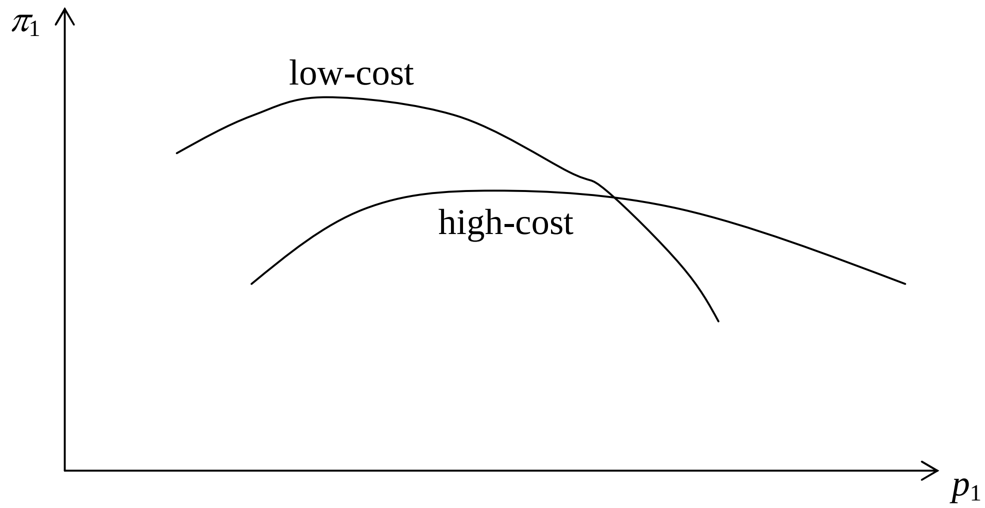
Could it be possible for a high-cost firm 1 to set a price in period 1 that is so high that a low-cost firm 1 would not want to mimic it?

– Yes, because increasing the price is less costly for a high-cost firm than for a low-cost firm.

$\pi_1 = (p_1 - c_1)D_1(p_1, p_2)$

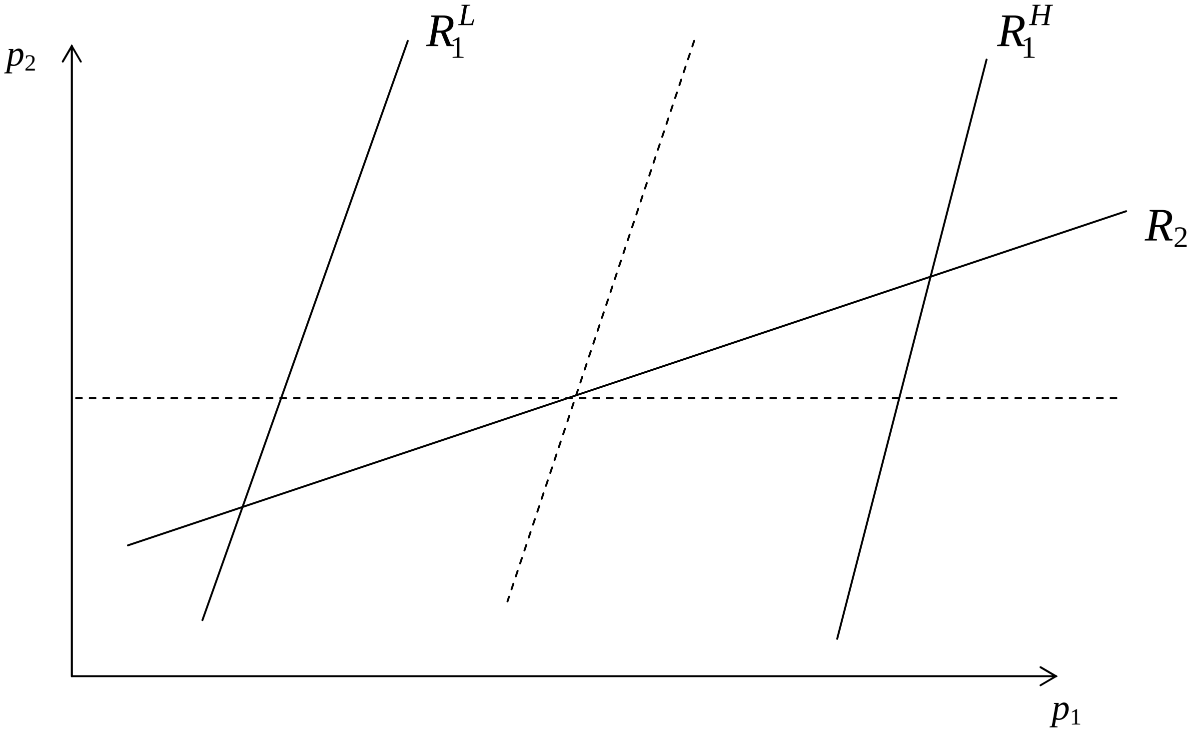
$$\frac{\partial^2 \pi_1}{\partial p_1 \partial c_1} = -\frac{\partial D_1}{\partial p_1} > 0$$

The effect on firm 1's profit of a price increase depends on the firm's costs. The higher costs are, the stronger is the effect if it is positive, and the weaker is the effect if it is negative.



A *separating equilibrium* is one where firm 1's price in period 1 depends on its costs.

A *pooling equilibrium* is one where firm 1's price in period 1 is the same whether it is low-cost or high-cost.



If firm 1's price in period 1 reveals its costs, then there is complete information in period 2.

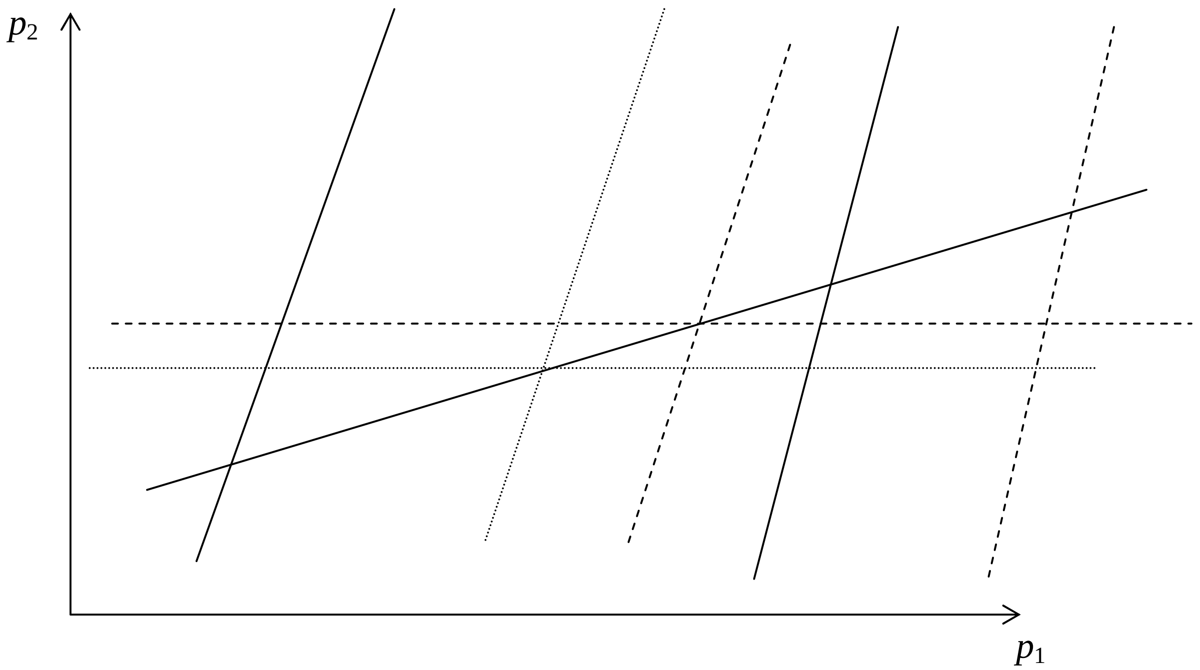
If firm 1's price in period 1 is uninformative of its costs, then the period-2 game is as in the static model.

Firm 1 would want firm 2 to believe it is high-cost, whether this is true or not.

Firm 2 will only believe firm 1 is a high-cost firm if it sets a price in period 1 that is so high that a low-cost firm would never set it – even though, by doing so, it would be considered a high-cost firm in period 2.

Thus, in a separating equilibrium, the high-cost best-response curve in period 1 is further to the right than in the static model.

Therefore, the expected best-response curve shifts to the right, and all prices are higher in period 1 of the two-period model than in the static model.



An extension: each firm has private information about own costs. The result that prices are higher still holds.
[Mailath, "Simultaneous Signaling in an Oligopoly Model", *Quart J Econ* 1989]

High-cost firm sets high price today in order to induce a high price tomorrow. → Puppy Dog strategy

<u>Entry deterrence</u>

Top Dog strategy

Two periods. Firm 1 has private information about own costs.

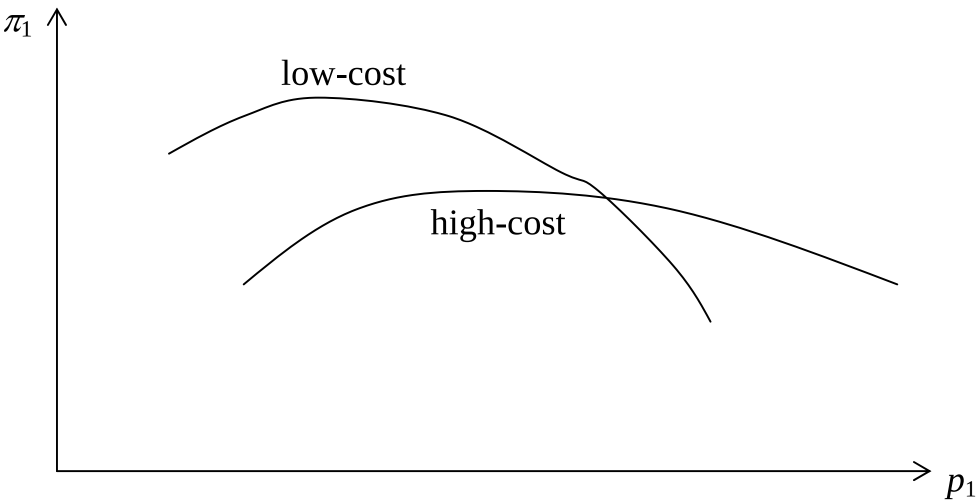
Period 1: Firm 1 is monopolist. It cannot deter entry through capacity investments, etc. Can it deter entry through its period-1 price?

Firm 1 wants firm 2 to believe its costs are low.

$$\frac{\partial \pi_2}{\partial c_1} > 0, \quad \frac{\partial E\pi_2}{\partial x} < 0$$

The interesting case: Entry is profitable for firm 2 if firm 1 has high costs but not if it has low costs.

Reducing the price is less costly for a low-cost firm than for a high-cost firm.



Complete information:
Period-1 price is the monopoly price.

Incomplete information: One of two situations may occur.

(i) Low-cost firm 1 sets a price below its monopoly price, in order to signal its low costs.
- Separating equilibrium

(ii) Both types of firm 1 set the low-cost monopoly price.
- Pooling equilibrium
- Can only happen if firm 2, without any new information, is deterred from entry.

Limit pricing: Price reduction to deter entry.

Is limit pricing credible?

In case (i), it is. The price reduction in the separating equilibrium serves to inform the potential entrant that entry is not profitable because of the presence of a very potent incumbent.

In case (ii), it is not. However, the outside firm hasn't learned anything during period 1 and therefore chooses to stay out.

What are the *welfare consequences* of incomplete information?

In both cases: Expected price lower because of incomplete information.

In case (i) – separating equilibrium – entry behaviour is unaffected by incomplete information. Thus, with a separating equilibrium, incomplete information is good for welfare.

In case (ii) – pooling equilibrium – the high-cost firm 1 manages to deter entry by mimicking the low-cost type. Thus, incomplete information implies less entry. Total effect on welfare is unclear.

What if the entrant does not know its own costs? Suppose firms' costs are the same, but only firm 1 knows what they are.

$$\frac{\partial \pi_2}{\partial c} < 0$$

Firm 1 wants to signal high costs in order to deter entry. Now, the high-cost firm sets price above monopoly in order to deter entry.

Puppy Dog as entry deterrence.

[Harrington, "Limit Pricing When the Potential Entrant Is Uncertain of Its Cost Function", *Econometrica* 1986]