

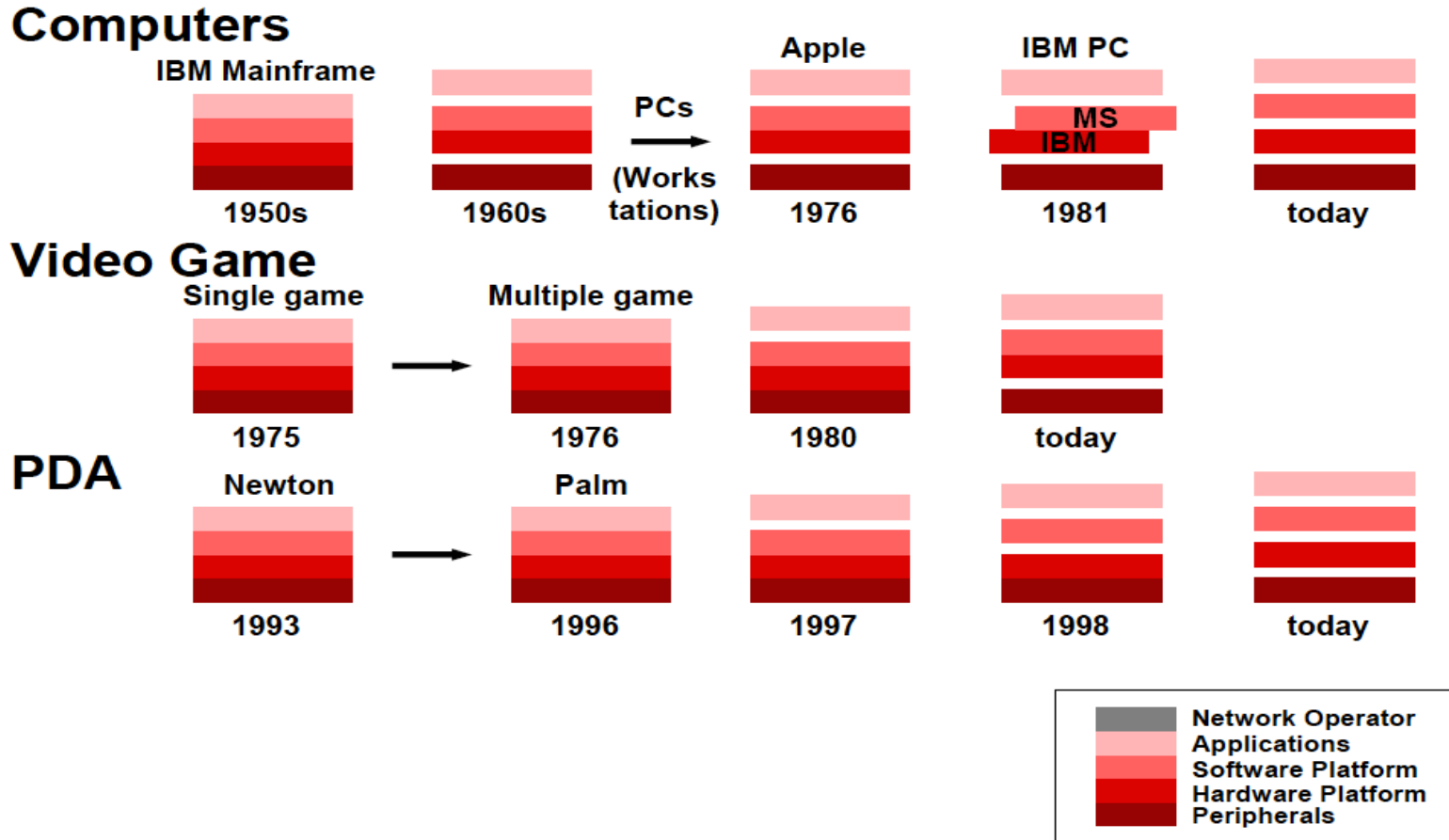
# Competing Complements

Ramon Casadesus-Masanell   Barry Nalebuff   David Yoffie

# Motivation I

- Industries such as computing, videogames, or telephone/handsets have moved away from vertically integrated to 'horizontal'

# “Horizontalization”



# Motivation II

- The trend towards 'horizontalization' has led to:
  - Competition *between* complements
  - Competition *within* complements



# Motivation II

- The trend towards 'horizontalization' has led to:
  - Competition *between* complements
  - Competition *within* complements



# Motivation III

- Competition between complementors
  - Well understood since Cournot (1838)
    - $q=1-(p_i+p_m)$
  - Main result: same profit (even if different cost)
    - Profit =  $D(p_i+p_m)*(p_i-c_i)$ .  
FOC:  $D'*(p_i-c_i)+D=0$ .  
Therefore,  $D'*(p_i-c_i)+D=D'*(p_m-c_m)+D$ . Therefore,  
 $(p_i-c_i)*D=(p_m-c_m)*D$
  - In our motivating example  $\rightarrow \pi_m = \pi_i$

# The Data

<b>Year</b>	<b>Total PCs Shipped</b>	<b>MS Revenue from OS</b>	<b>Intel's Gross Margin</b>	<b>Immediate delta of Intel over MS</b>	<b>Delta profit / pc</b>
1986	5,087,500	\$ 104,940,000	\$ 339,360,000	\$ 234,420,000	\$46.08
1987	9,435,000	\$ 169,540,000	\$ 724,920,000	\$ 555,380,000	\$58.86
1988	12,950,000	\$ 277,770,000	\$ 1,149,960,000	\$ 872,190,000	\$67.35
1989	14,892,500	\$ 353,760,000	\$ 1,181,040,000	\$ 827,280,000	\$55.55
1990	16,927,500	\$ 461,370,000	\$ 1,672,440,000	\$ 1,211,070,000	\$71.54
1991	18,685,000	\$ 663,480,000	\$ 2,068,920,000	\$ 1,405,440,000	\$75.22
1992	28,305,000	\$ 1,351,910,000	\$ 2,761,080,000	\$ 1,409,170,000	\$49.79
1993	38,295,000	\$ 1,276,020,000	\$ 4,645,200,000	\$ 3,369,180,000	\$87.98
1994	44,215,000	\$ 1,534,170,000	\$ 4,993,800,000	\$ 3,459,630,000	\$78.25
1995	55,592,500	\$ 2,077,950,000	\$ 7,048,440,000	\$ 4,970,490,000	\$89.41

# So, why not same profit?

- Intel makes money from flow
- MS makes money from flow and stock

$$\pi_i = D(p_i + p_m) * (p_i - c_i)$$

$$\pi_m = D(p_i + p_m) * (p_m - c_m)$$

where  $c_i > 0$  and  $c_m < 0$

...data does not show  $c_m$  revenue

# Motivation IV

- Competition within complements
  - Well-understood (many models available)
  - We focus on price competition with vertical product differentiation (motivated by Intel vs. AMD)

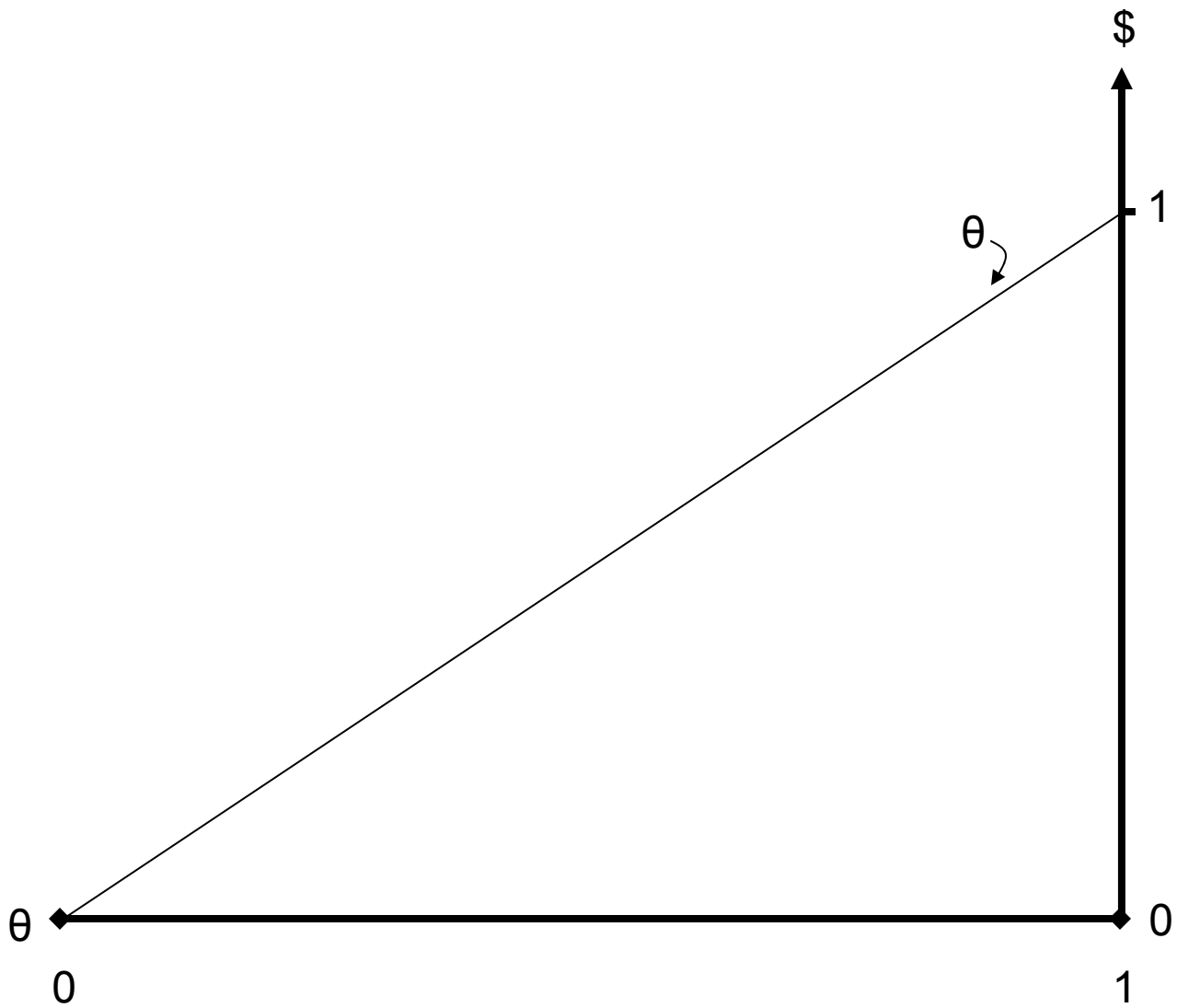
# Motivation V

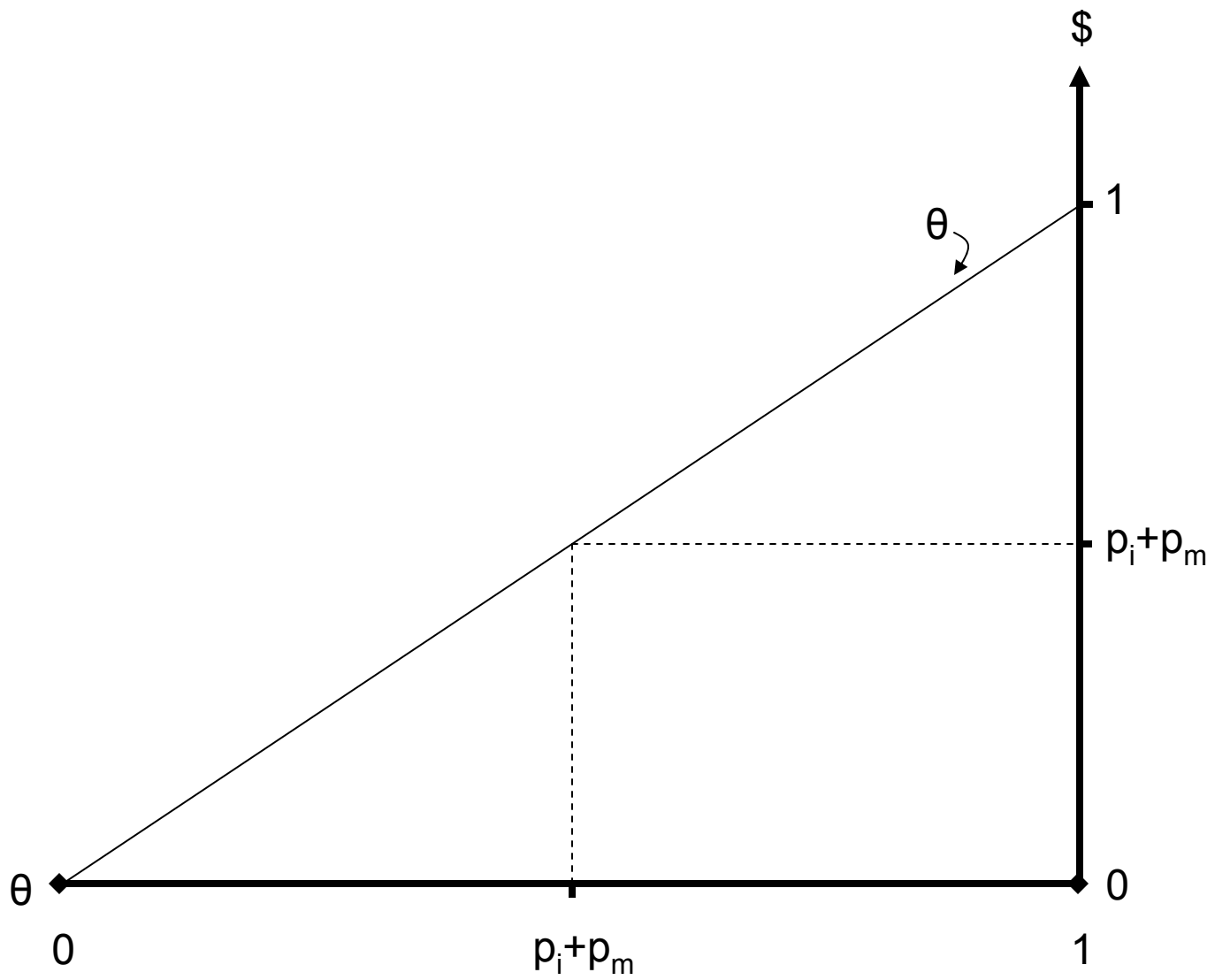
- The combined case has not been looked at, but most relevant
- We study competition in B (microprocessor) when there is a monopoly in A (OS)
- We find:
  - Interactions are potentially very complicated
  - Multiplicity of equilibria
  - A may prefer to interact with a monopoly in B
  - Less intense price competition in B enhances welfare

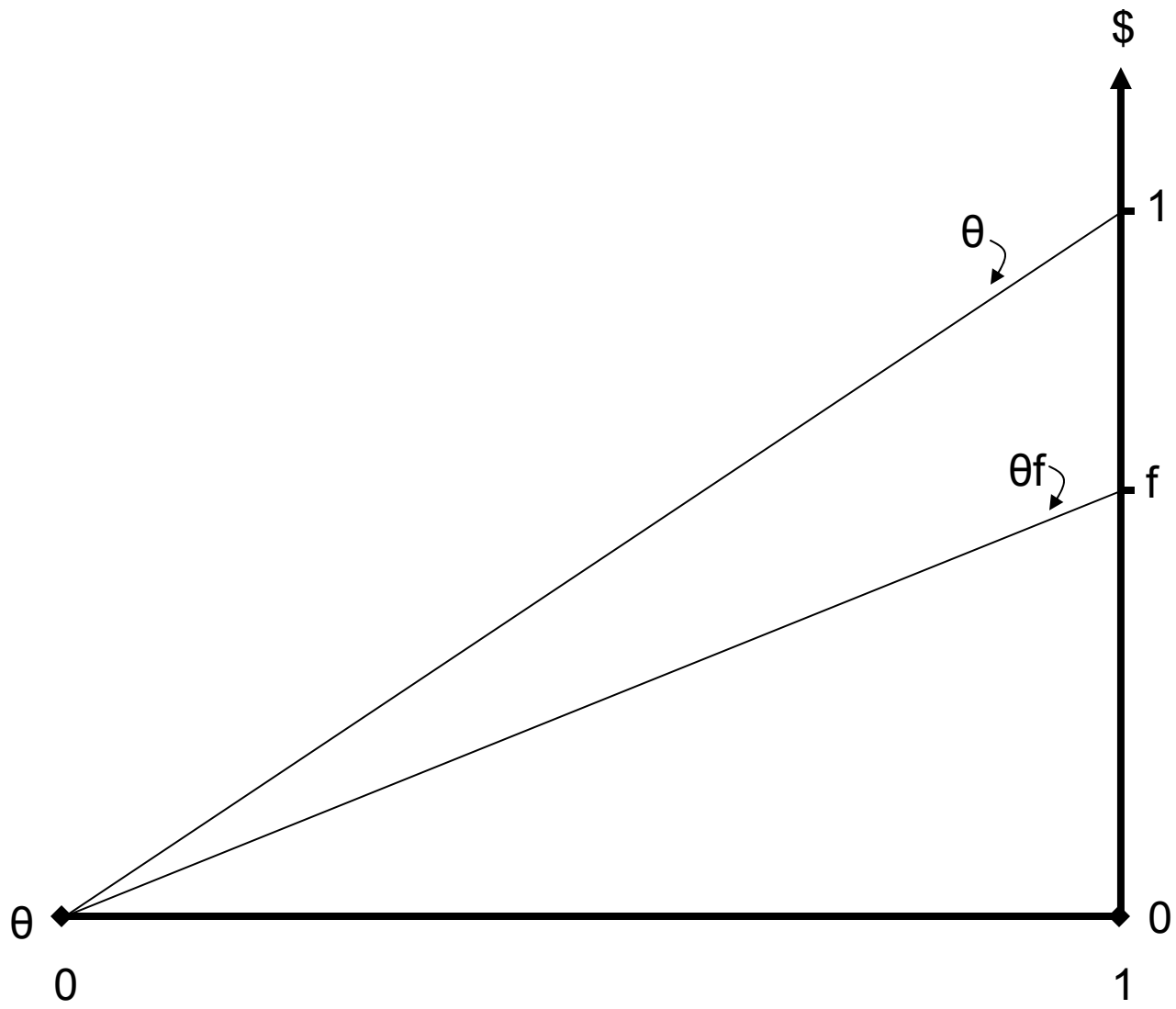
# Model

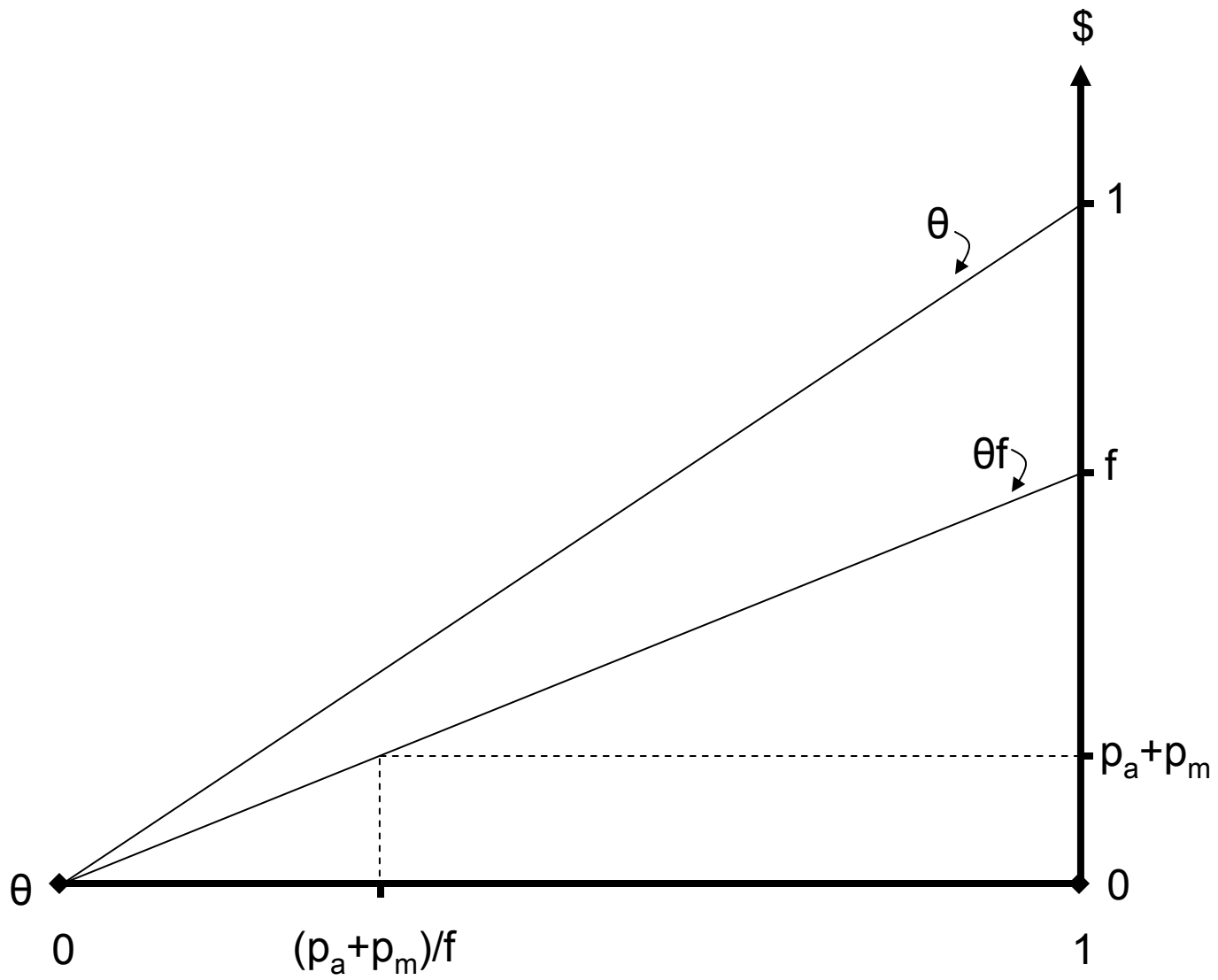
- Three players: Microsoft, Intel, AMD
- Demand for PCs (OS + microprocessor):
  - Customers indexed by  $\theta \sim U[0,1]$
  - Customer  $\theta$  values MS/Intel at  $\theta$  and MS/AMD at  $f*\theta$ , where  $0 < f < 1$
- $mc=0$
- Players choose price

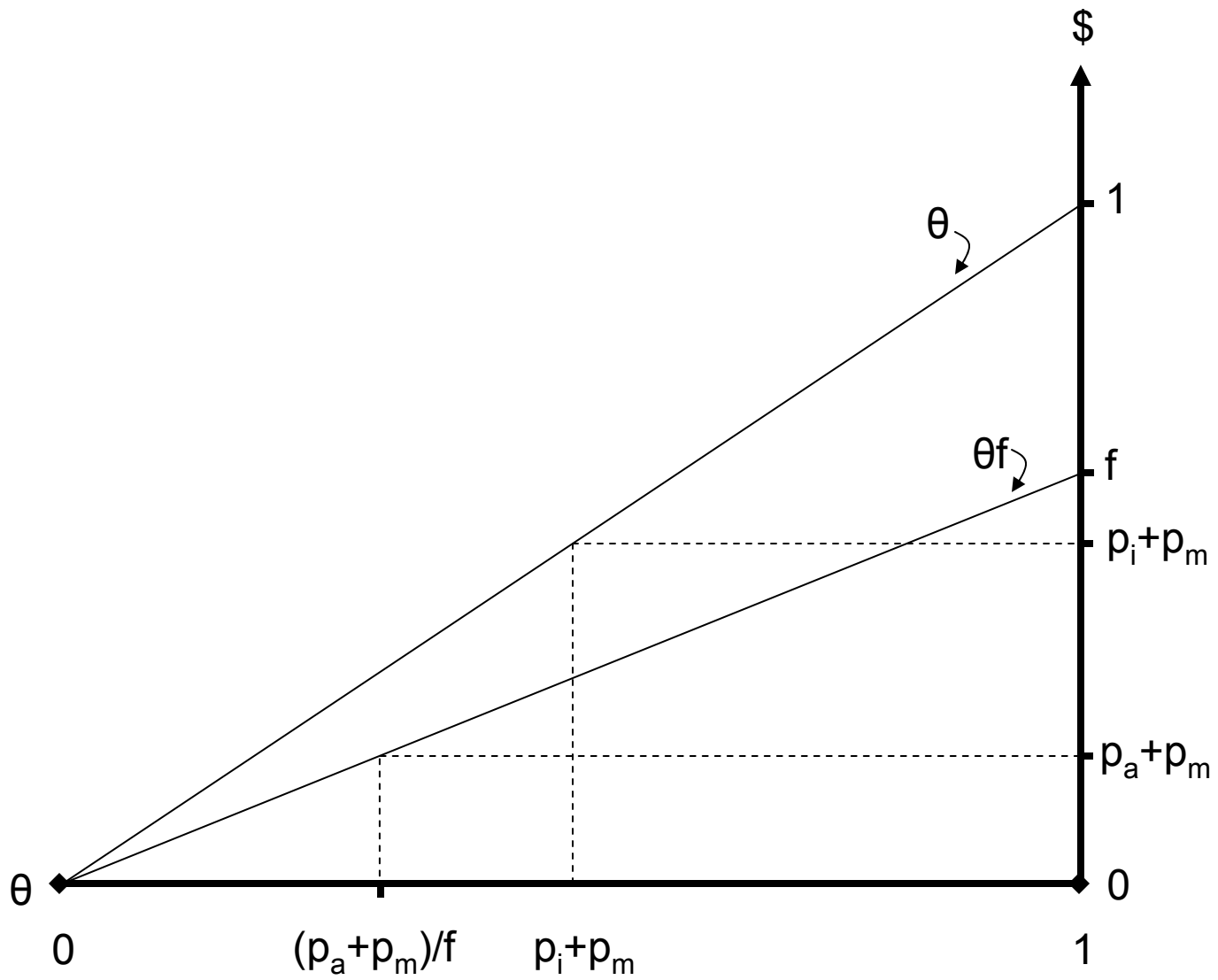


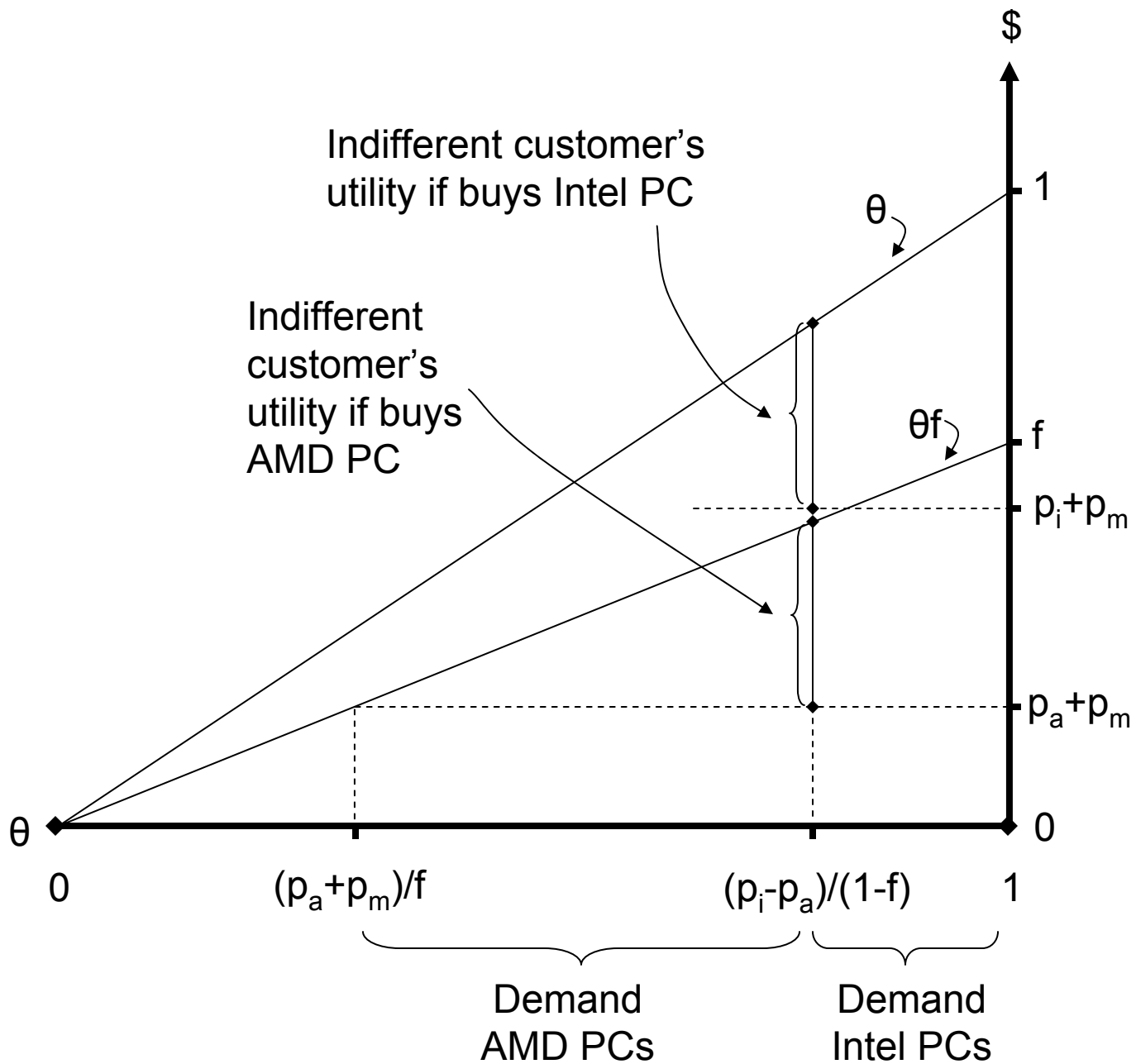


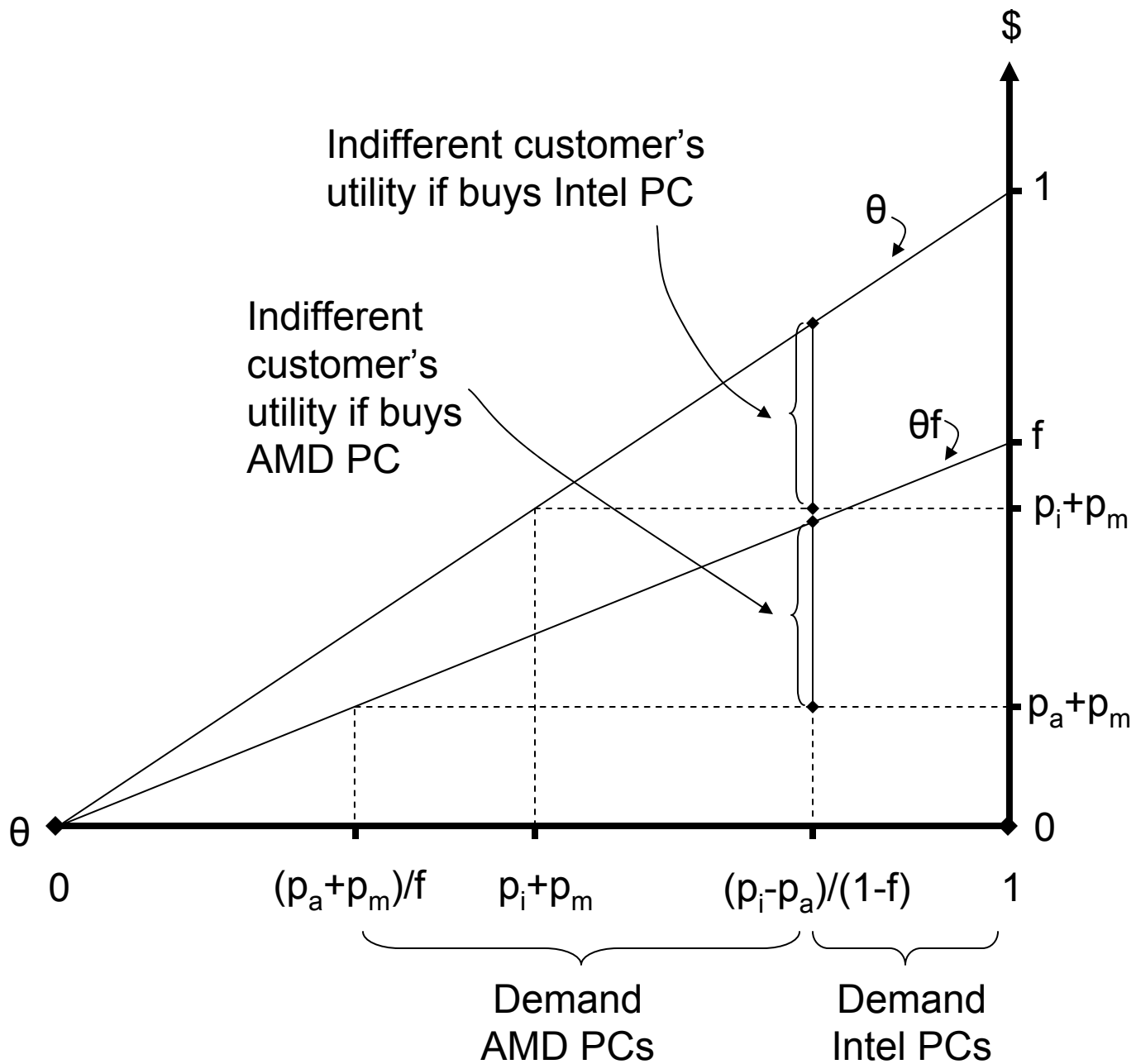












# Demand (summary)

- Two-player world:

$$q_m = q_i = 1 - p_m - p_i$$

- Three-player world:

$$q_m = 1 - (p_a + p_m)/f \quad q_i = 1 - (p_i - p_a)/(1-f)$$

$$q_a = (p_i - p_a)/(1-f) - (p_a + p_m)/f$$

# Result 0: No p.s. eq. with $q_a > 0$

- With zero costs, there is no pure-strategy equilibrium in which AMD obtains positive demand
- Proof:
  - Get best responses with three
  - Solve for  $p_m$ ,  $p_i$ , and  $p_a$  to get:  $p_m = f/2$ ,  $p_i = (1-f)/2$ ,  $p_a = 0$
  - Substitute into  $q_a$  to obtain  $q_a = 0$  and  $q_m = q_i = 1/2$  ■
- Whatever price AMD charges, resulting demand is so small that AMD would choose to lower its price. But that leads Intel to lower price and MS to raise price, squeezing AMD out of the market.

- Suppose  $p_a = x > 0$ . Then  $p_m = (f - p_a)/2 < f/2$  so that AMD has a positive price and positive demand.

MS will lower its price by  $x/2$  and Intel will raise its price by  $x/2$  -- due to strategic comp and sub. That means demand for AMD will be  $2x/(1-f)$ .

- AMD's foc will be  $fp_i - (1-f)p_m - 2p_a = x/2*(f + 1-f) - 2p_a \Rightarrow$   
Optimal  $p_a = x/4$ .
- So whatever price it charges, resulting demand is so small that AMD would choose to lower its price.

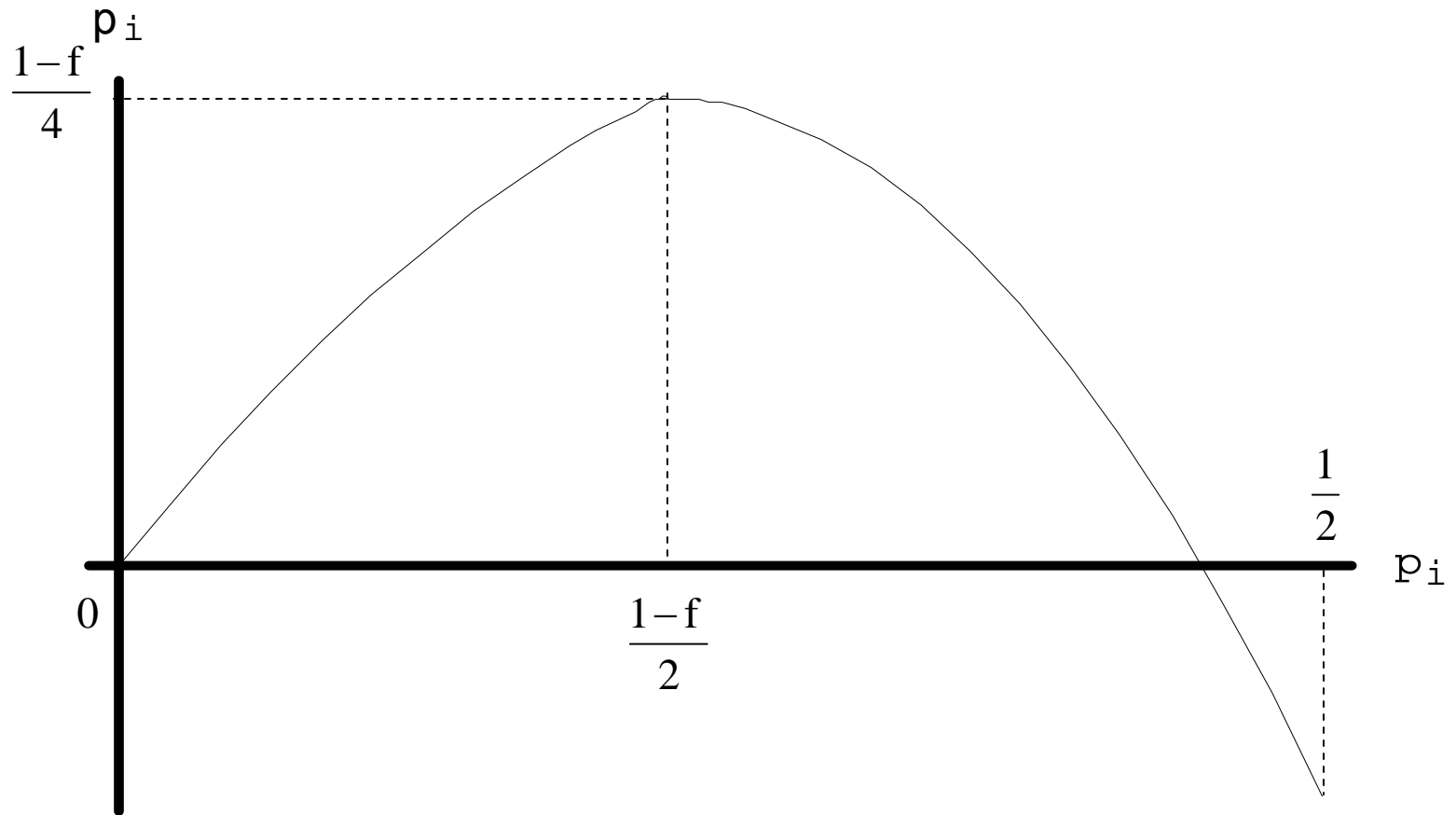
But that leads Intel to lower price and MS to raise price, squeezing AMD out of the market.

# Result 1: No 3-player eq.

- With zero costs, there is no pure-strategy equilibrium in which AMD is active
- Proof:
  - Only candidate is:  $p_m = f/2$ ,  $p_i = (1-f)/2$ ,  $p_a = 0$
  - Here  $q_a = 0$  (and  $q_m = q_i = 1/2$ ) and AMD is active at margin
  - The problem is  $p_m = f/2$  is not MS's best response
    - If  $p_i = (1-f)/2$  and  $p_a = 0$ , MS would be better off charging  $(1+f)/4$  (ignoring AMD). At  $p_m = (1+f)/4$  ( $> f/2$ ), AMD is shut out
  - Easy to see that MS makes more money at the deviation ■

## AMD active

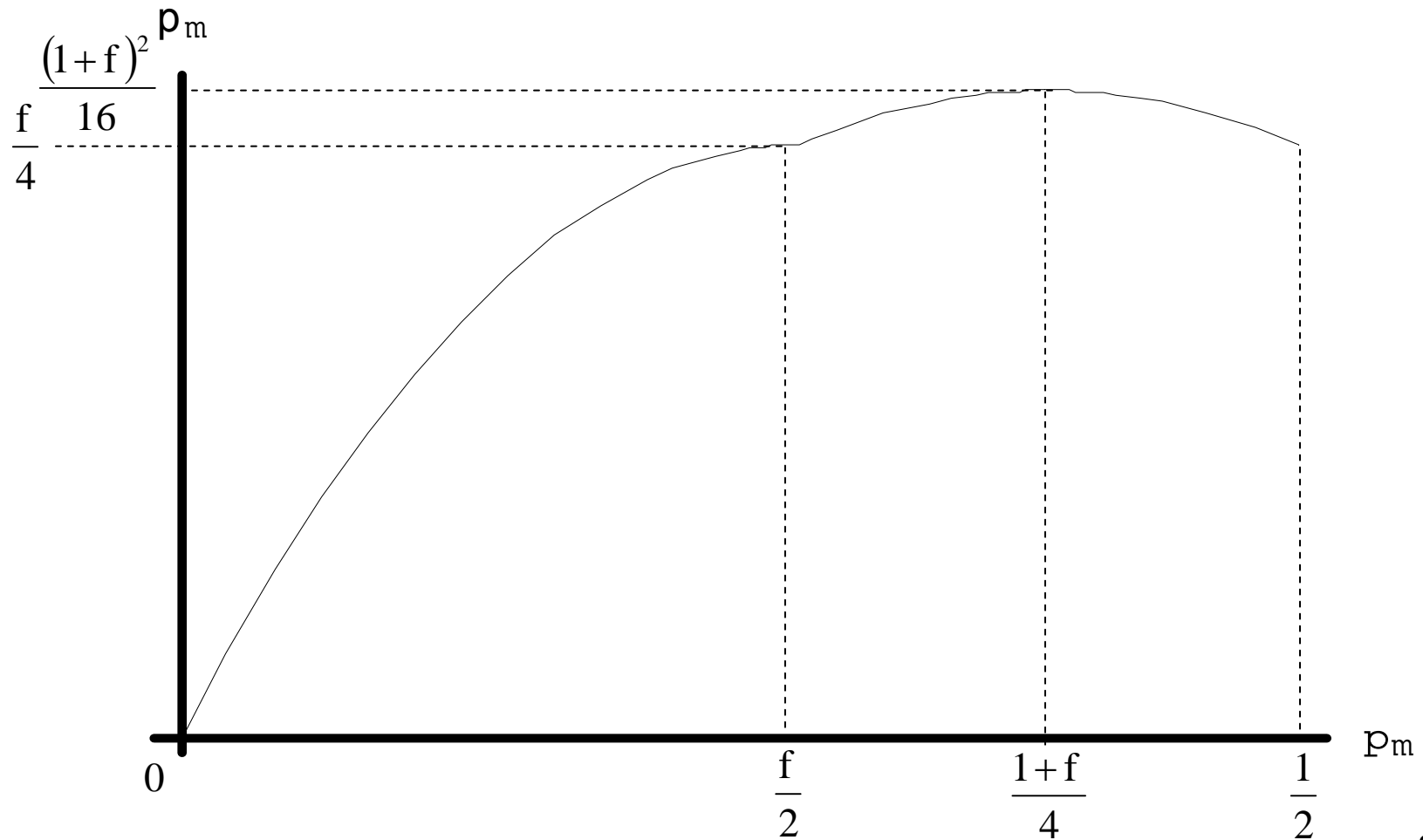
Intel's profit as a function of own price if MS and AMD stay put at the candidate prices for a three-player equilibrium



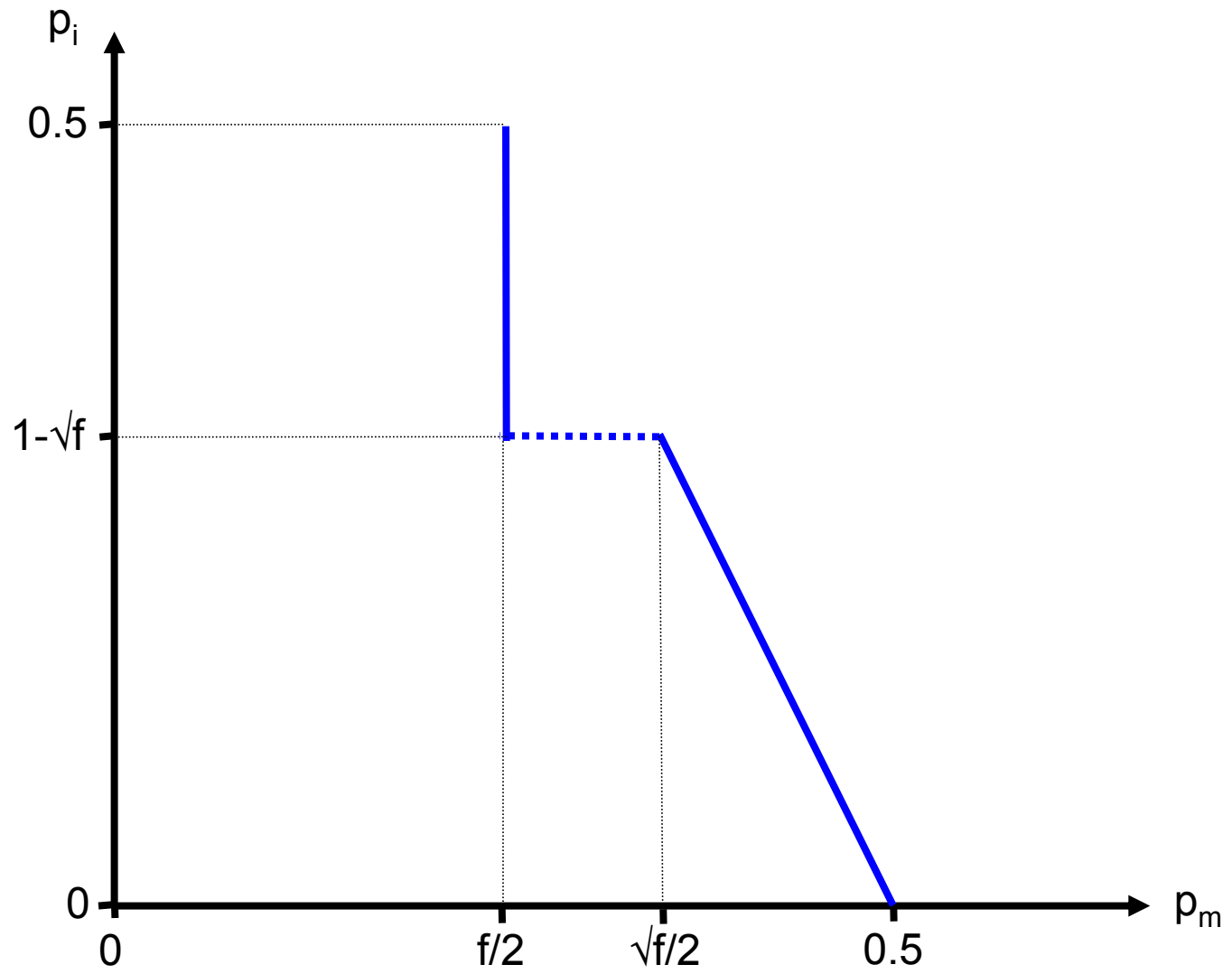
Equilibrium candidate:  $p_m = f/2$   $p_i = (1-f)/2$   $p_a = 0$

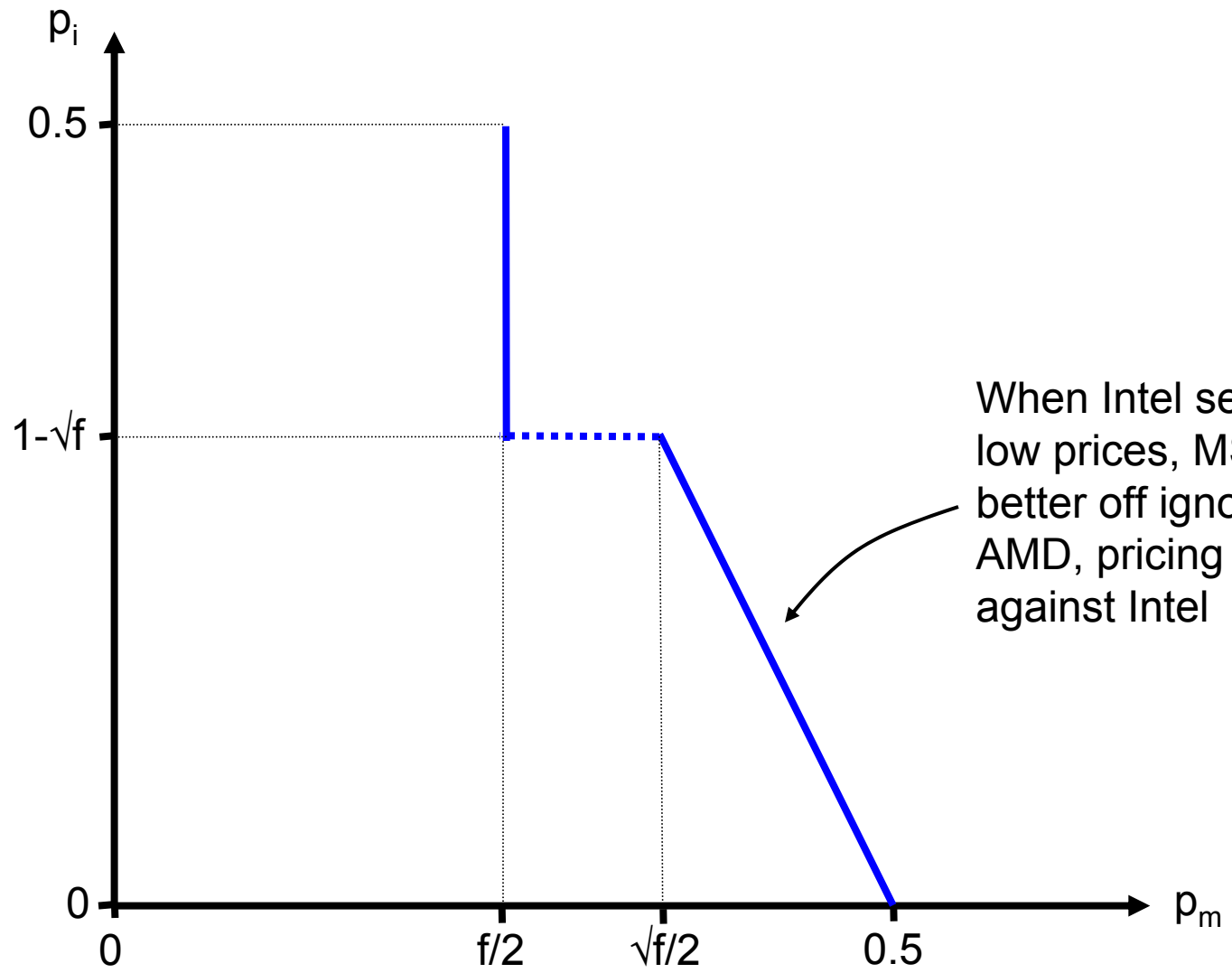
## AMD active

Microsoft's profit as a function of own price if Intel and AMD stay put at the candidate prices for a three-player equilibrium

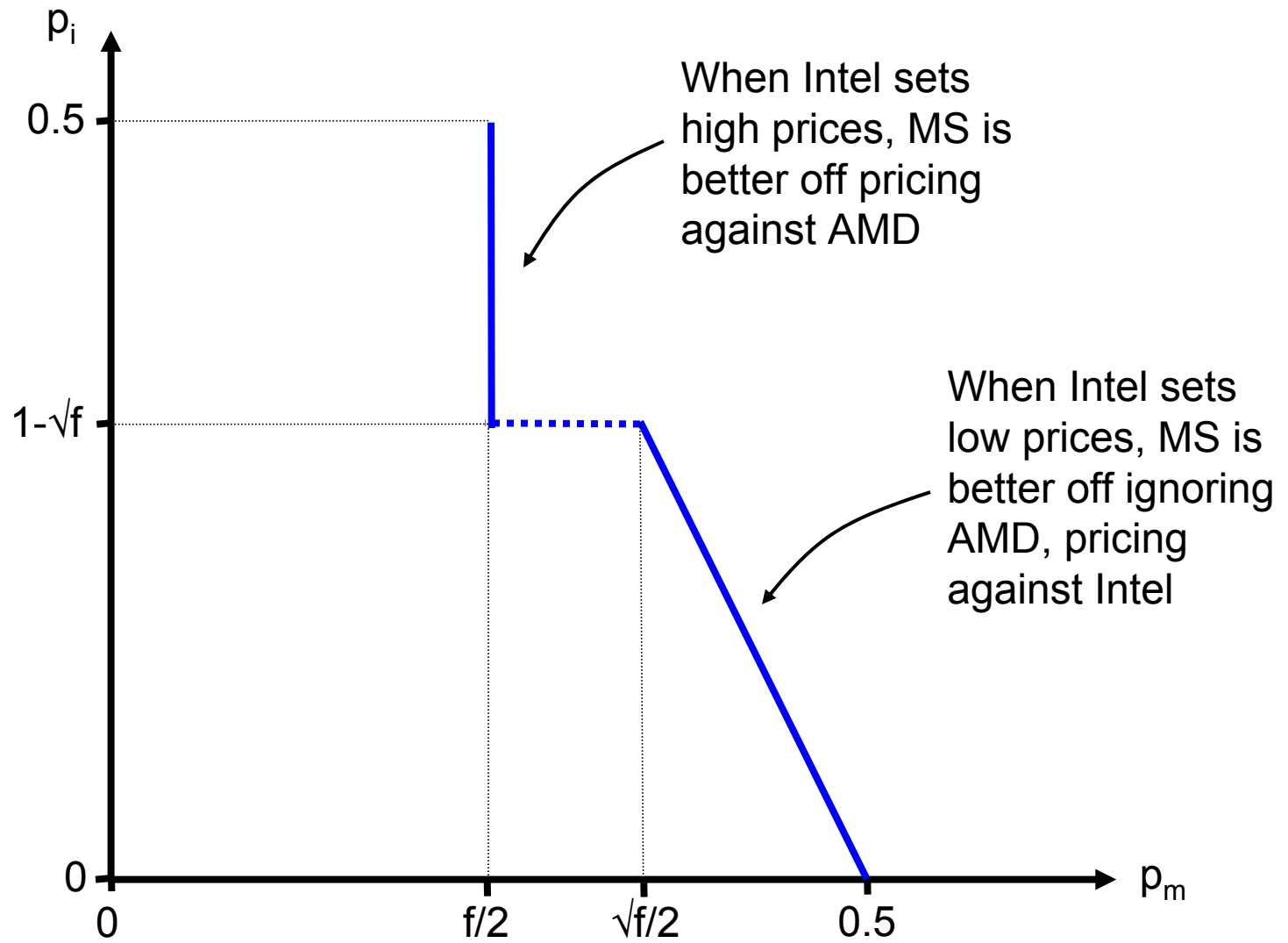


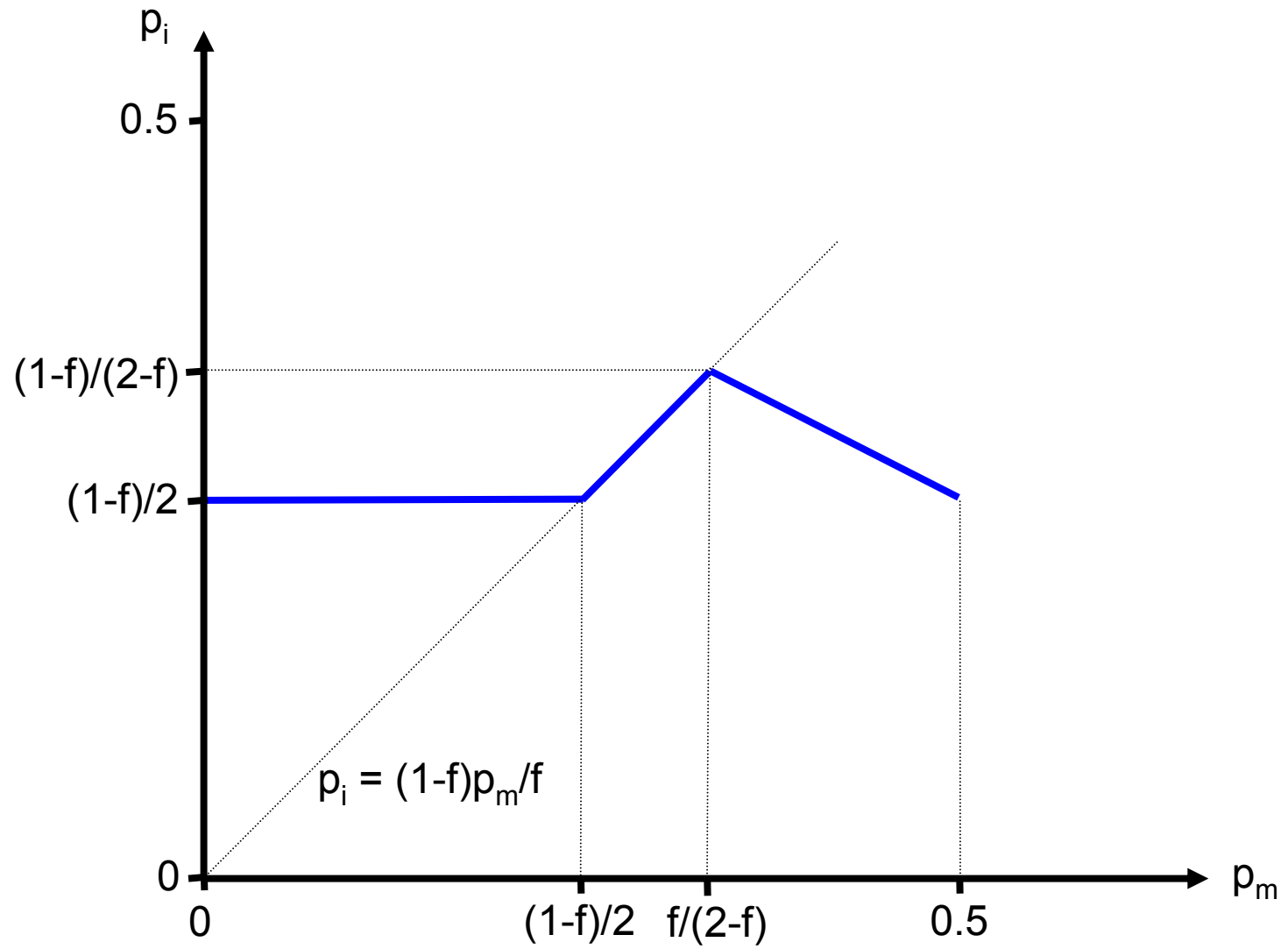
Equilibrium candidate:  $p_m = f/2$   $p_i = (1-f)/2$   $p_a = 0$

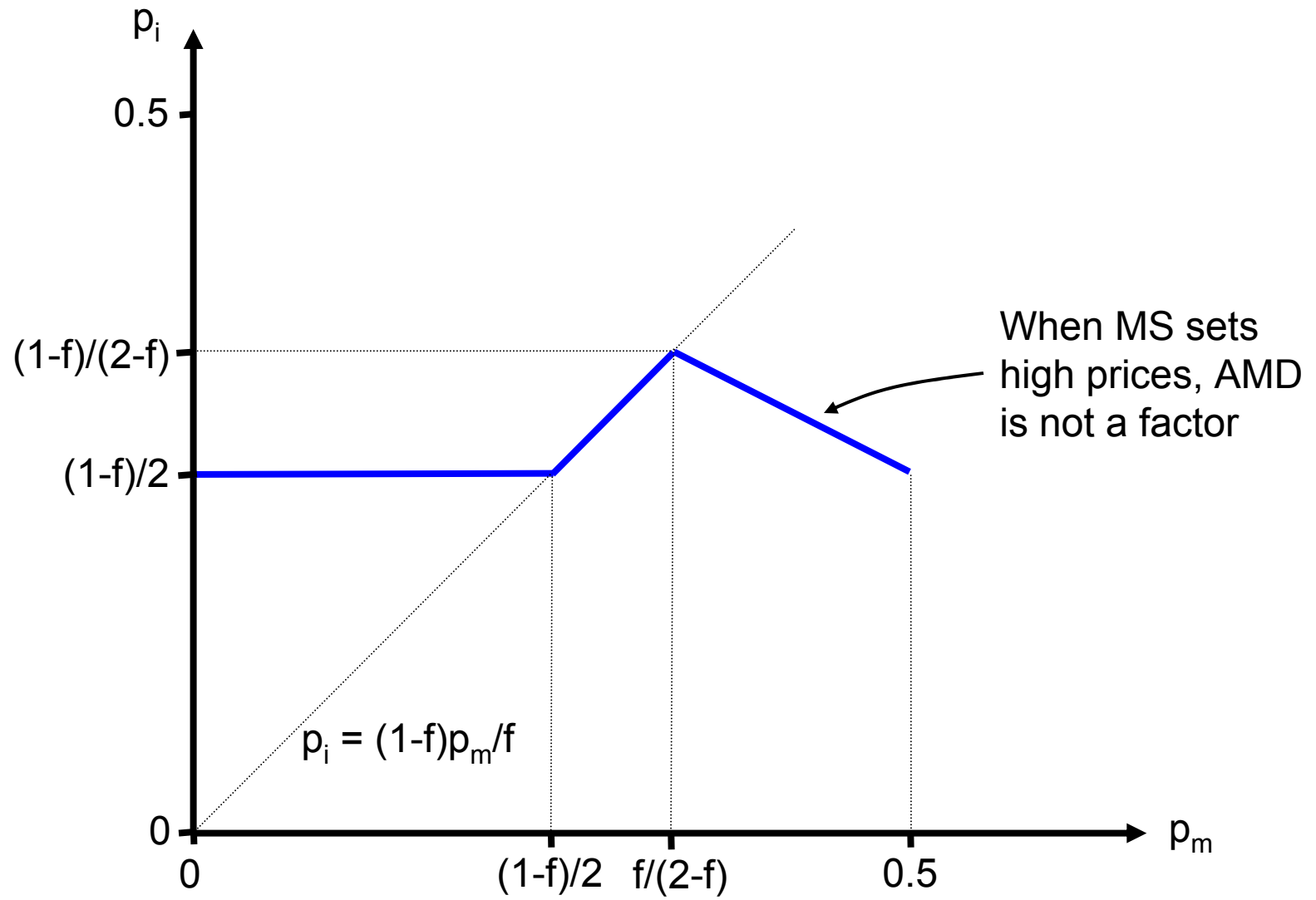


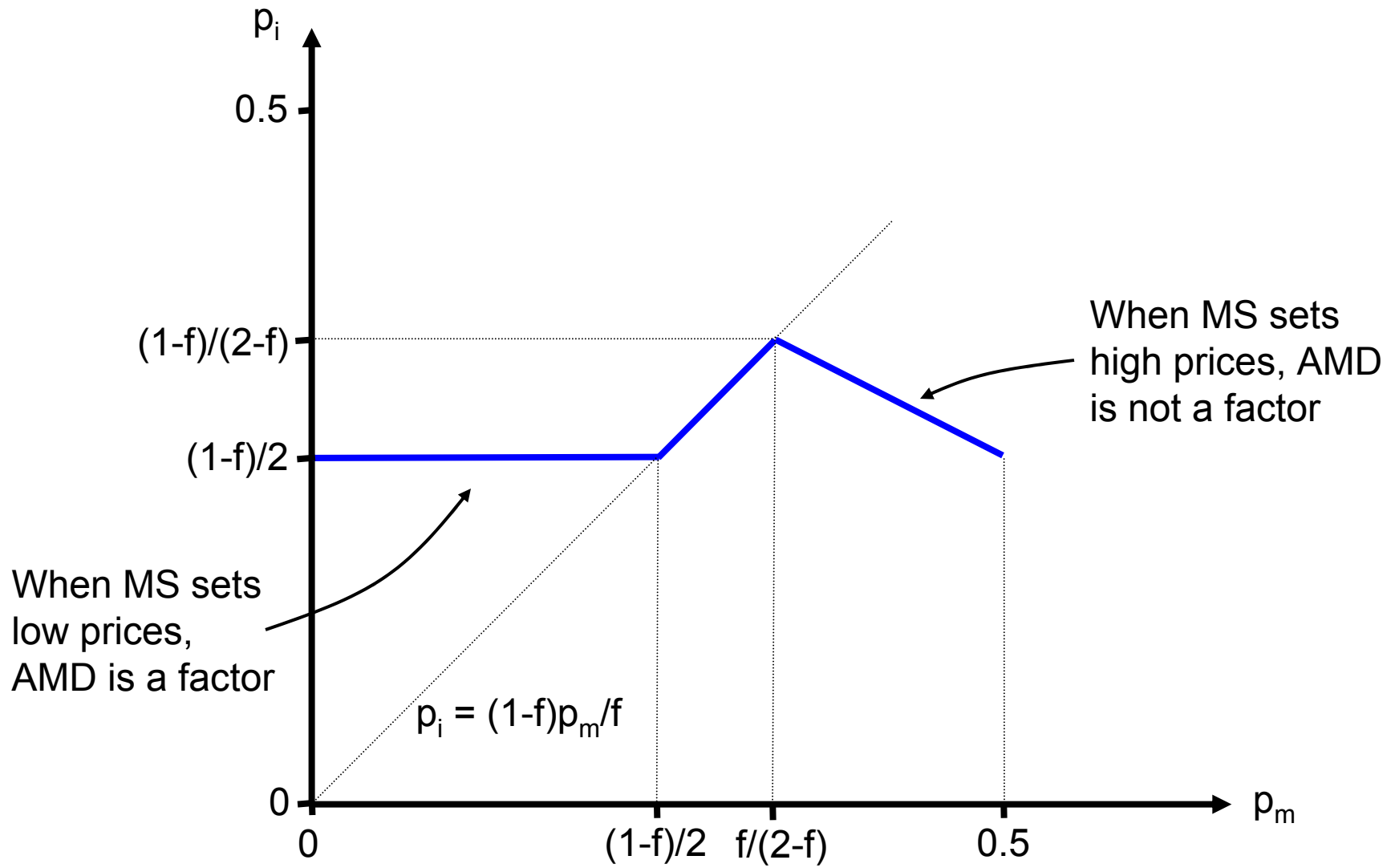


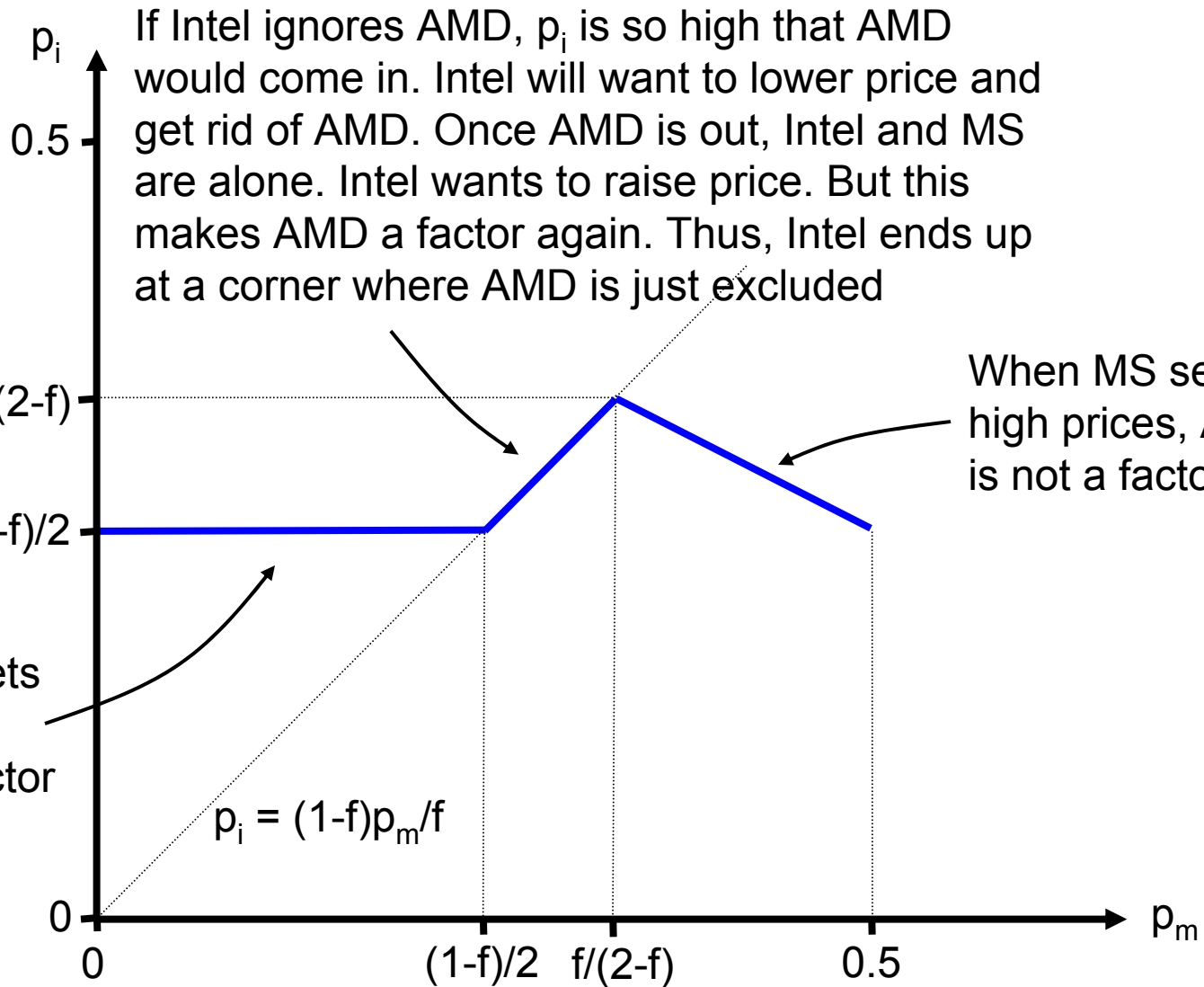
When Intel sets low prices, MS is better off ignoring AMD, pricing against Intel



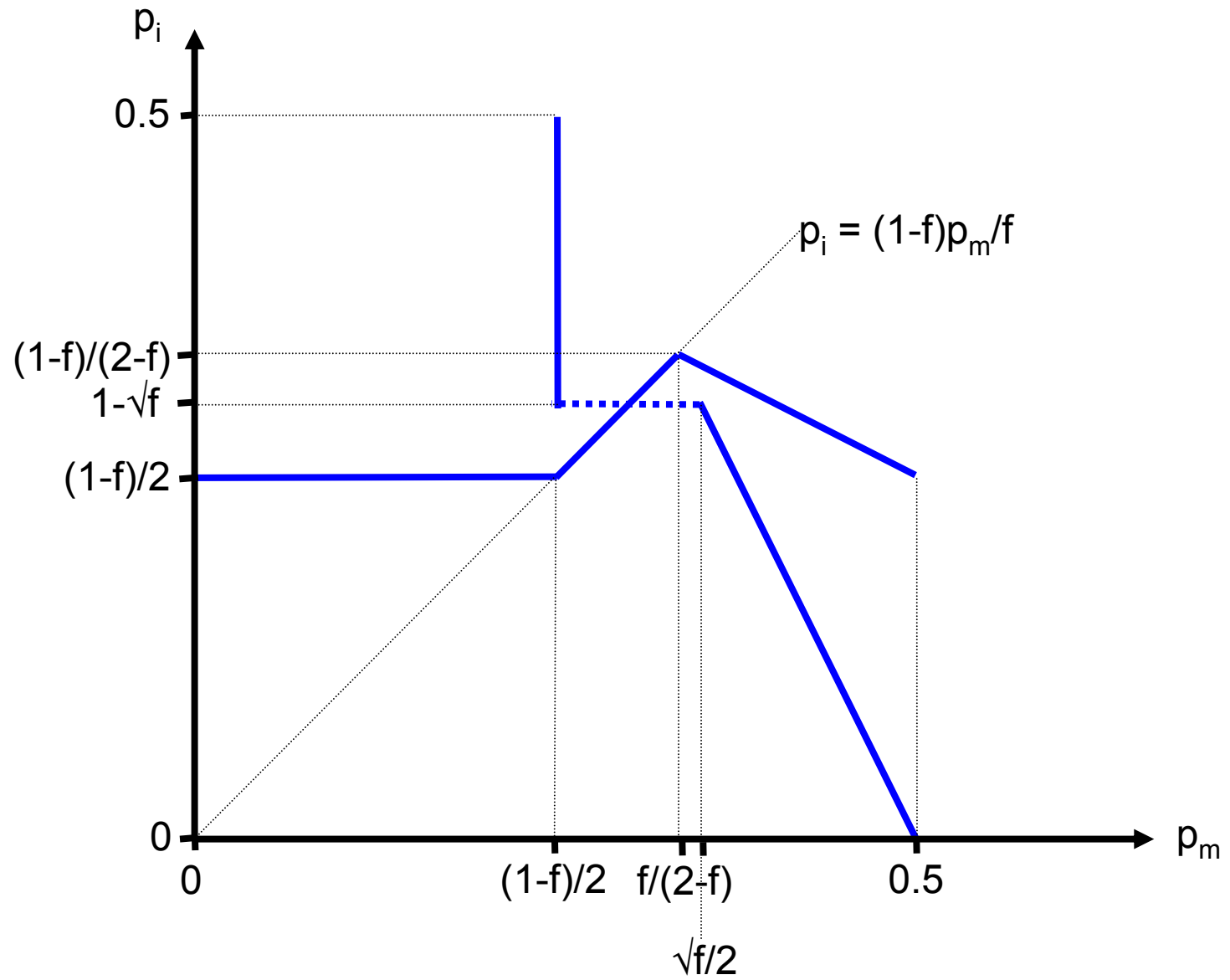


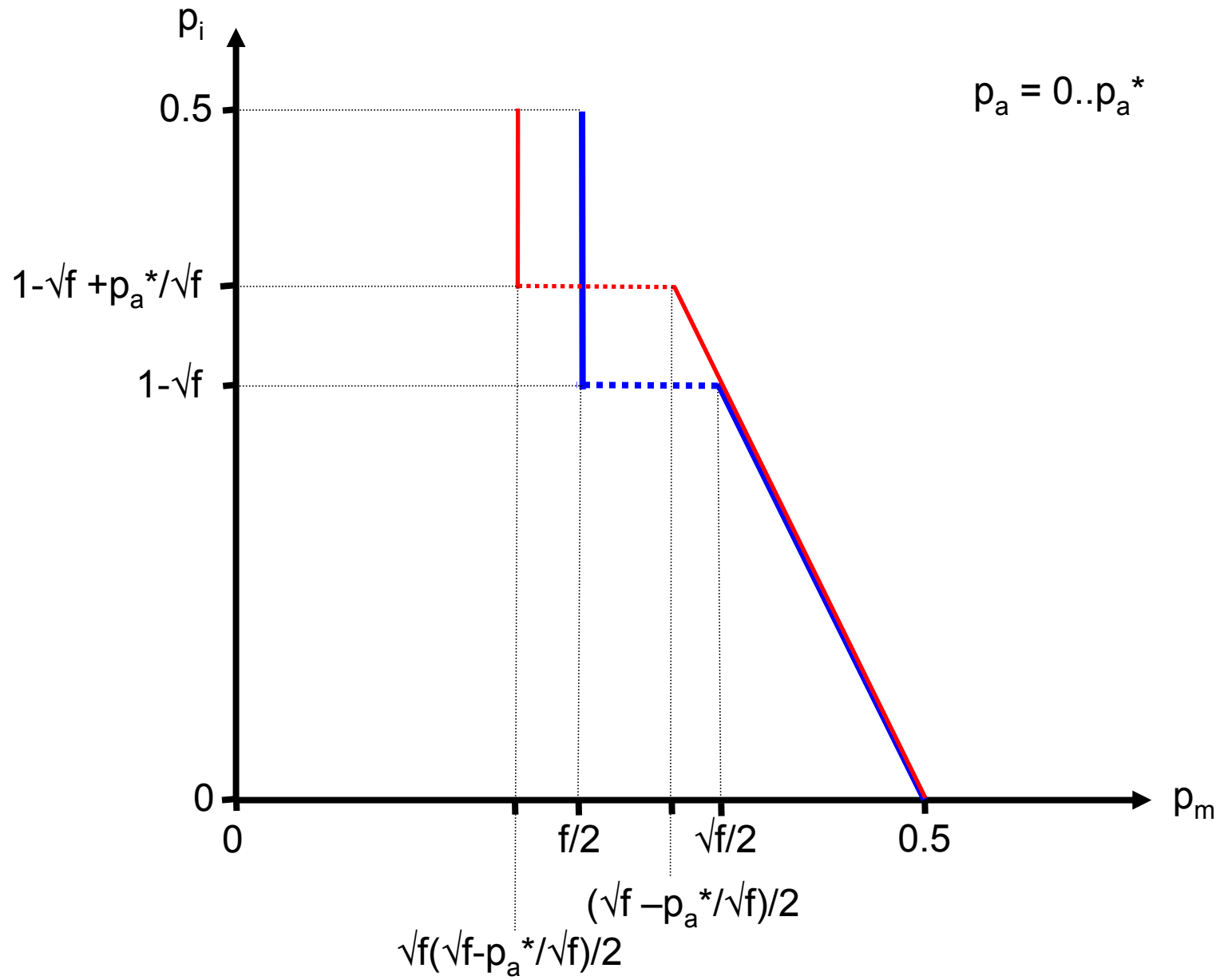


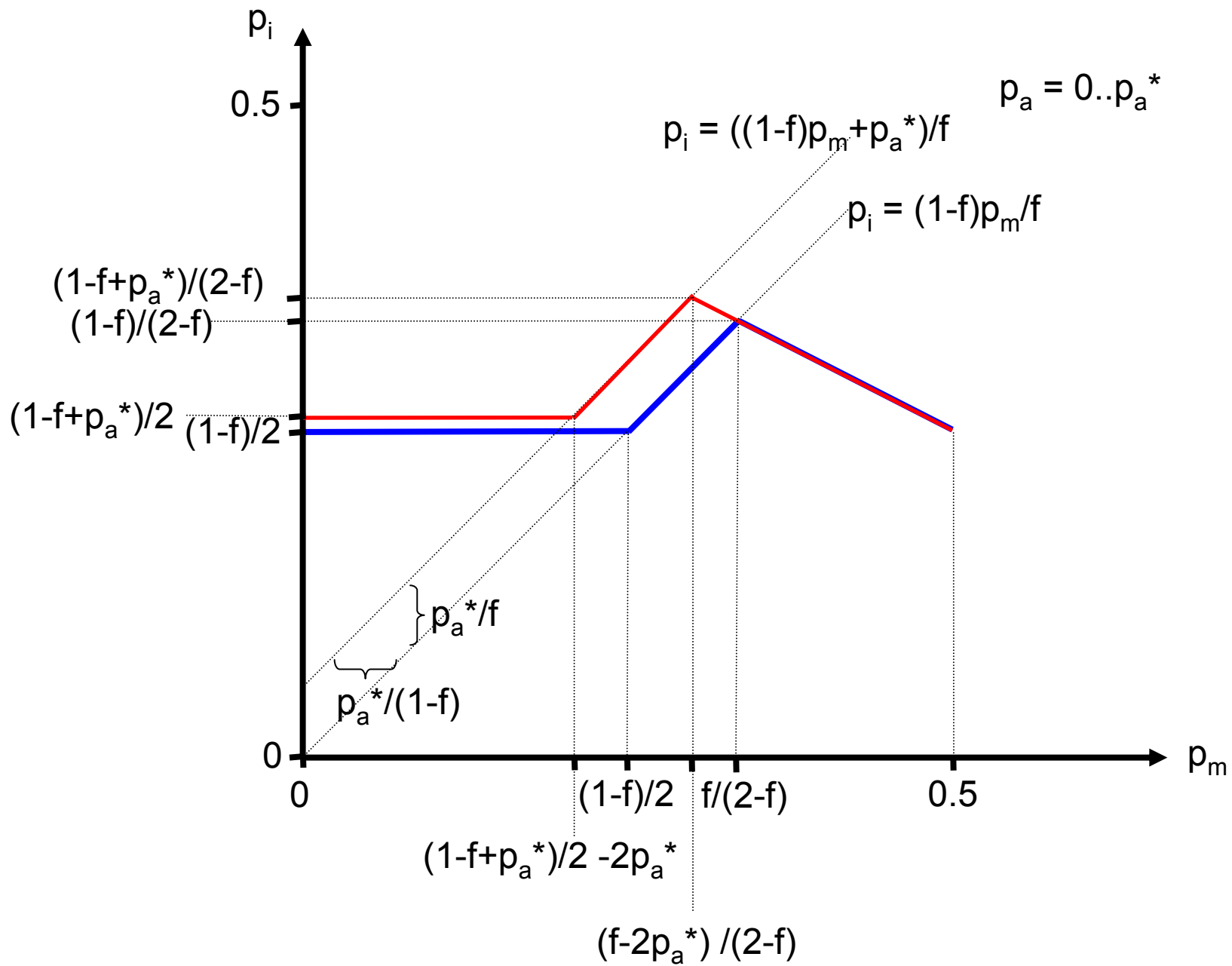


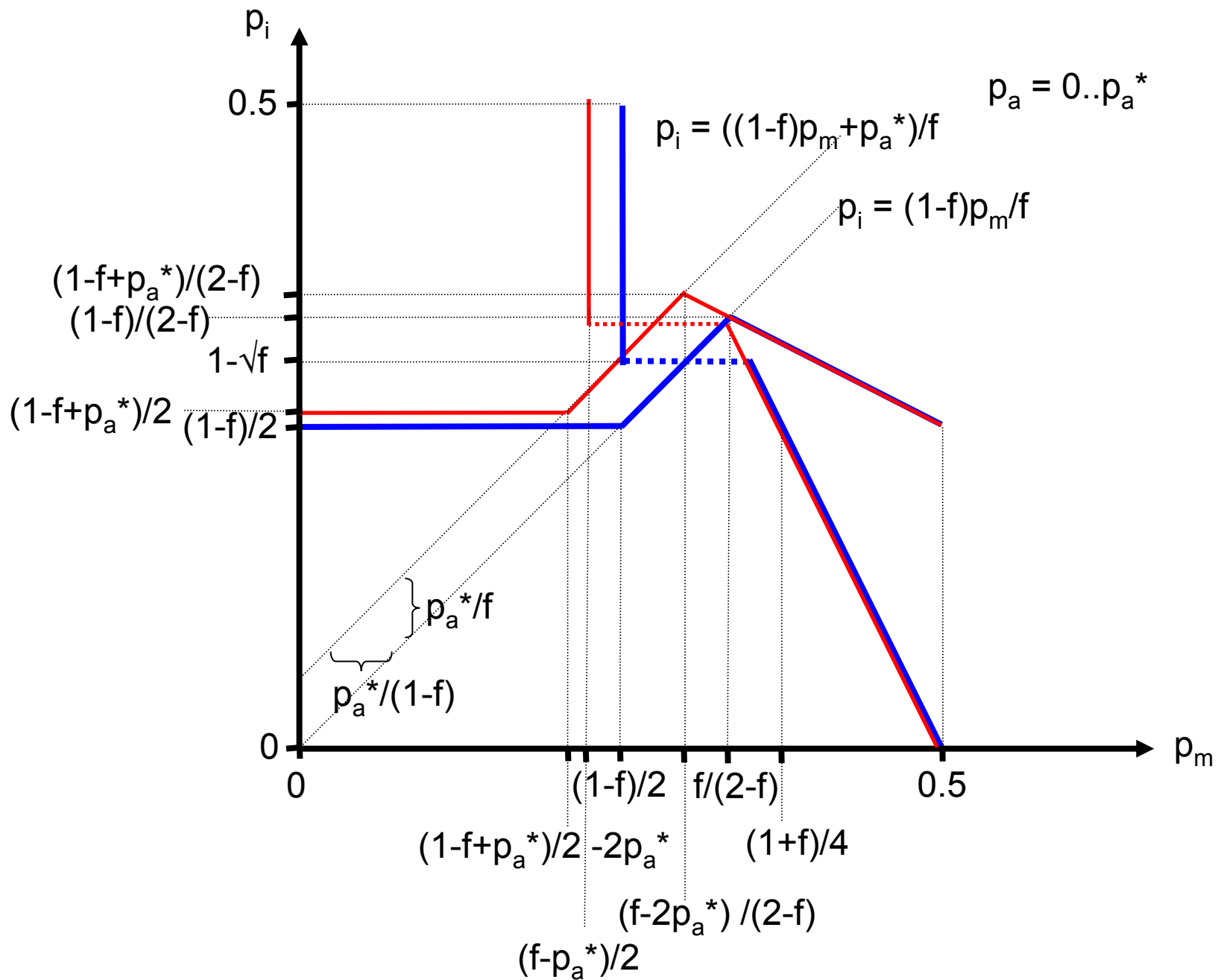


If Intel ignores AMD,  $p_i$  is so high that AMD would come in. Intel will want to lower price and get rid of AMD. Once AMD is out, Intel and MS are alone. Intel wants to raise price. But this makes AMD a factor again. Thus, Intel ends up at a corner where AMD is just excluded









# Assumption

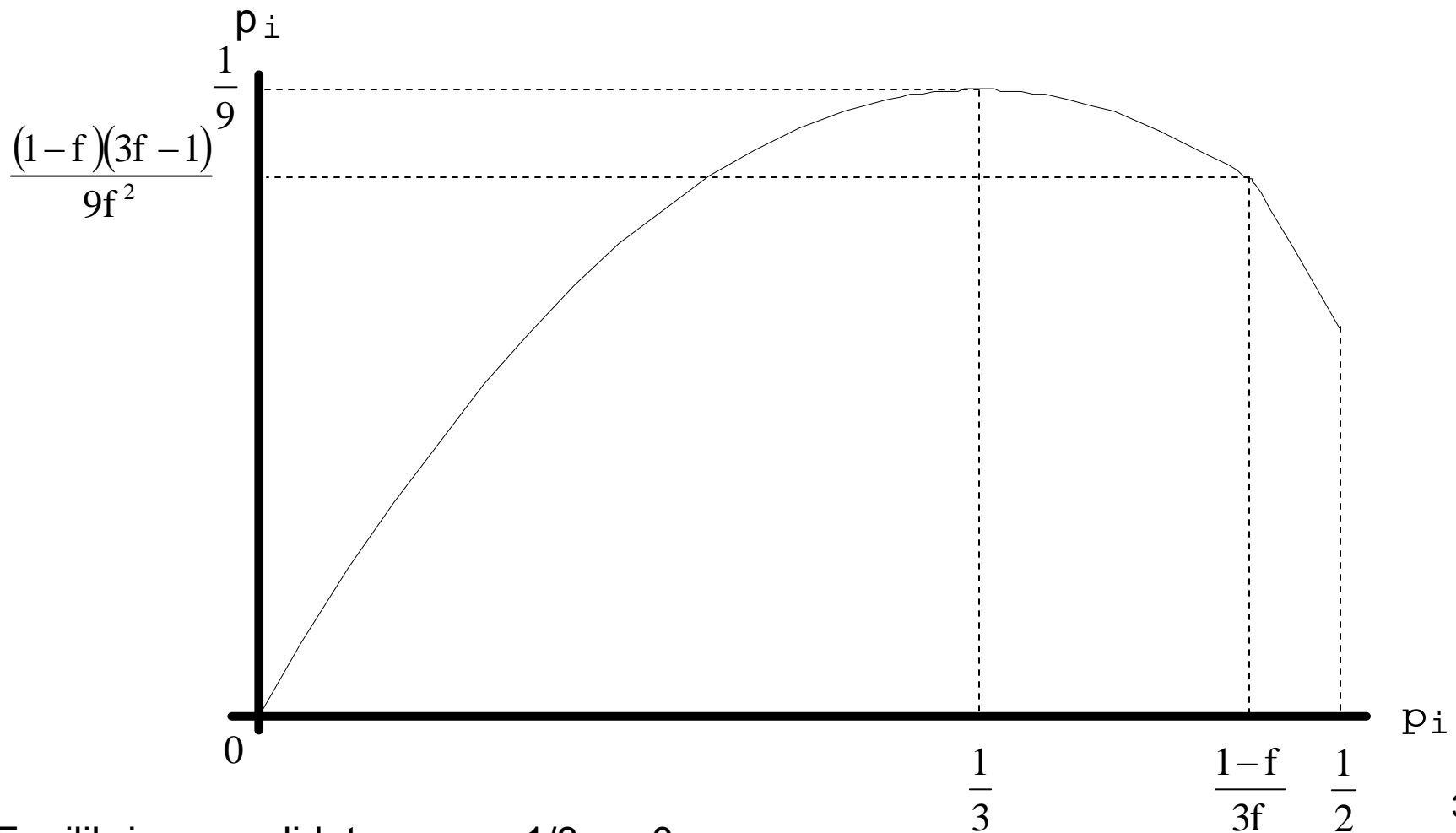
- When out, AMD is “charging” c

## Result 2: Eq. if $f \leq 4/9$

- When  $f \leq 4/9$ , the unique p.s. eq is: MS and Intel both charge  $1/3$ . AMD is inactive
- Proof:
  - Get best responses with two
  - Solve for  $p_m$  and  $p_i$  to get:  $p_m = p_i = 1/3$ . Profits are  $1/9$
  - Intel does not want to deviate
    - Lower price does not bring AMD in and lowers Intel's profit
    - Higher price brings AMD in but that is only worse than profit against MS alone
  - Will MS want to bring AMD in by lowering price?
    - At the deviation, MS profit is  $p_m(1-p_m/f)$  (assuming AMD sets  $p_a=0$ ). Best  $p_m = f/2$  and MS profit is  $f/4$ . Now compare to  $1/9$  to see that as long as  $f \leq 4/9$  MS does not want to deviate
  - Does AMD want to come in?
    - Need  $(p_i - p_a)/(1-f) < (p_a + p_m)/f$ . The worst case is  $f=4/9$ , but even in this case the inequality is satisfied for all  $p_a$ . So, we're ok ■

### AMD not active – Case 1 ( $0 < f < 4/9$ )

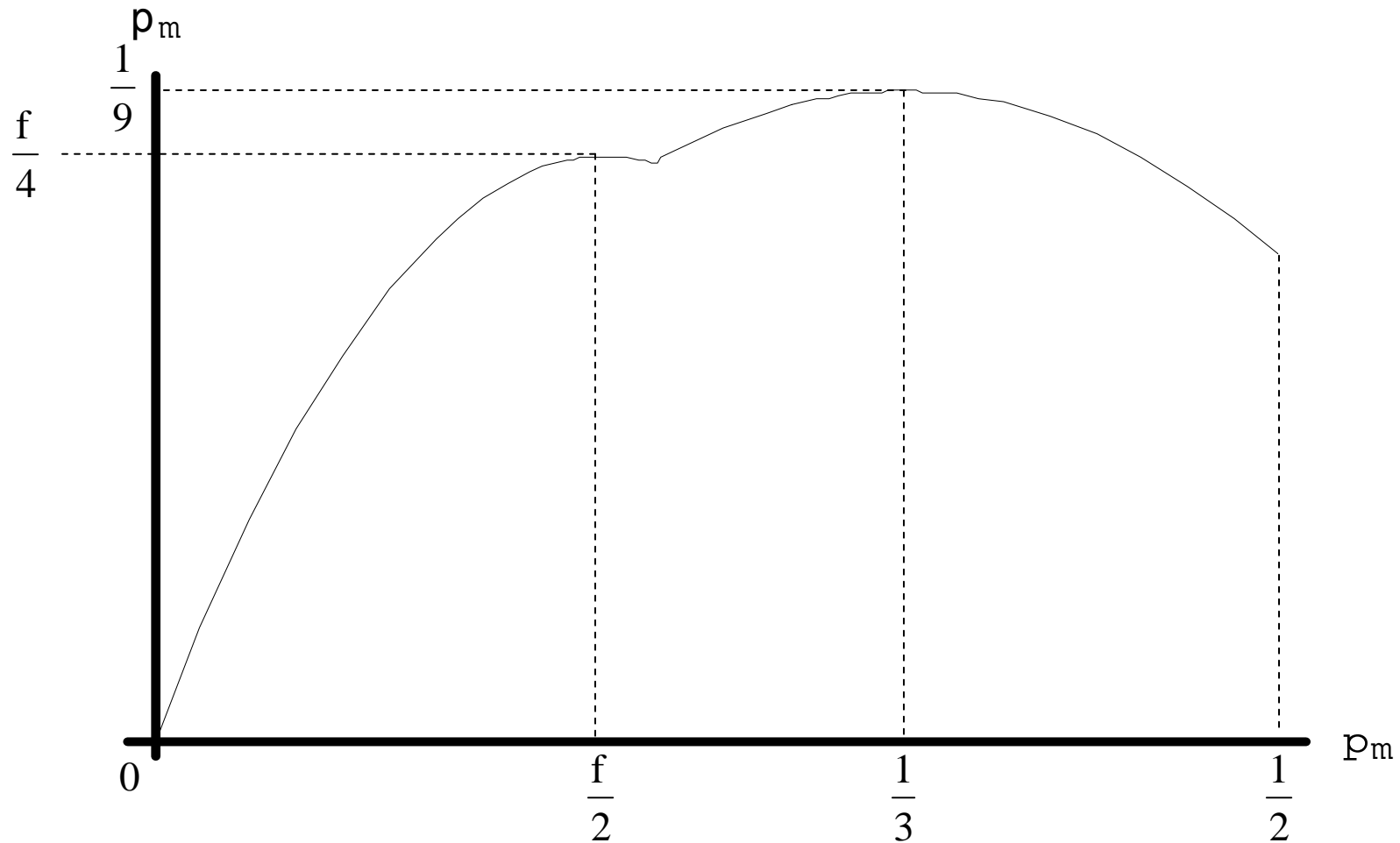
Intel's profit as a function of own price if MS stays put at the candidate price for a two-player equilibrium and AMD is out setting price equal to zero



Equilibrium candidate:  $p_i = p_m = 1/3$   $p_a = 0$

### AMD not active – Case 1 ( $0 < f < 4/9$ )

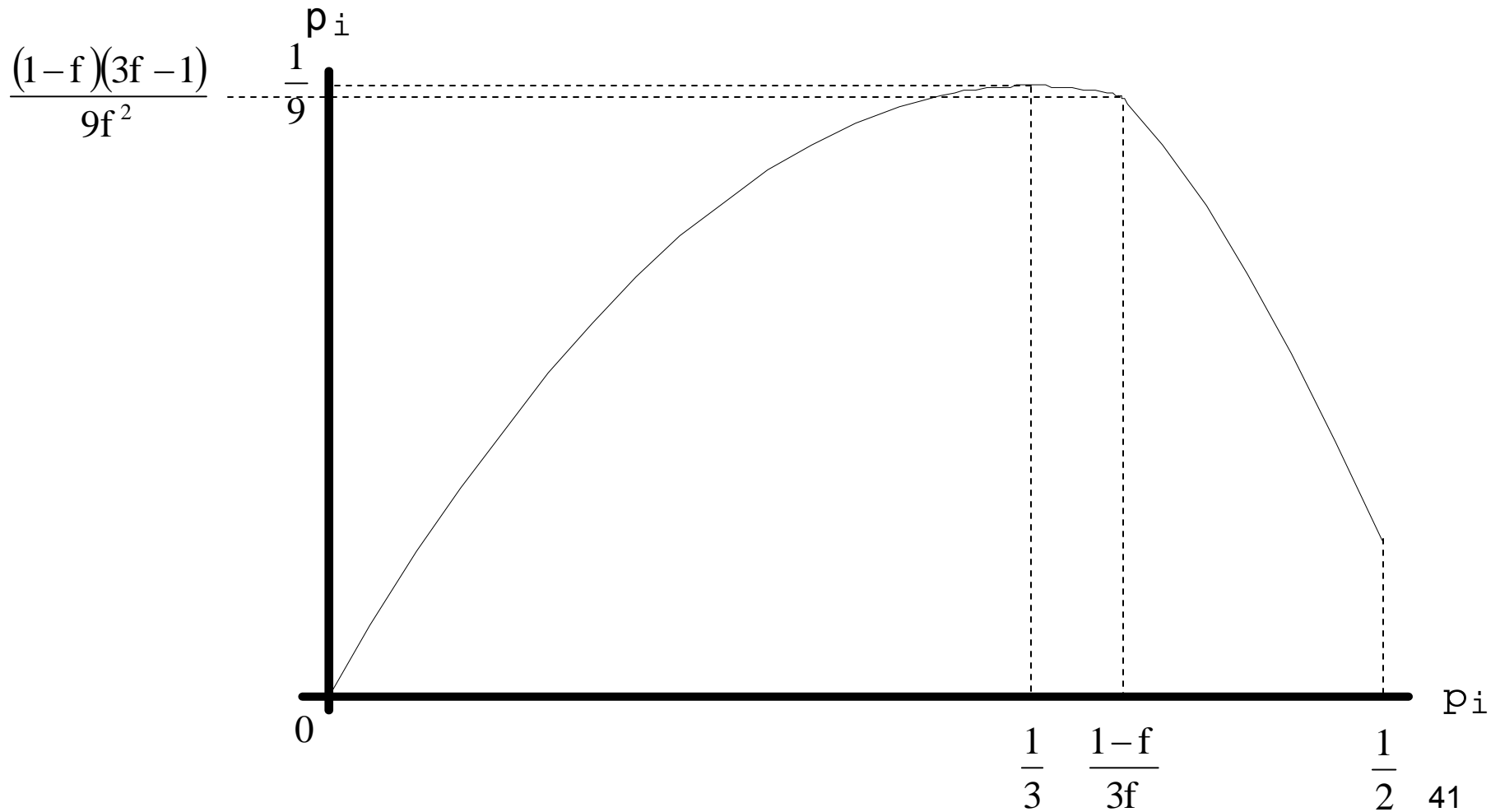
Microsoft's profit as a function of own price if Intel stays put at the candidate price for a two-player equilibrium and AMD is out setting price equal to zero



Equilibrium candidate:  $p_i = p_m = 1/3$   $p_a = 0$

## AMD not active – Case 2 ( $4/9 < f < 1/2$ )

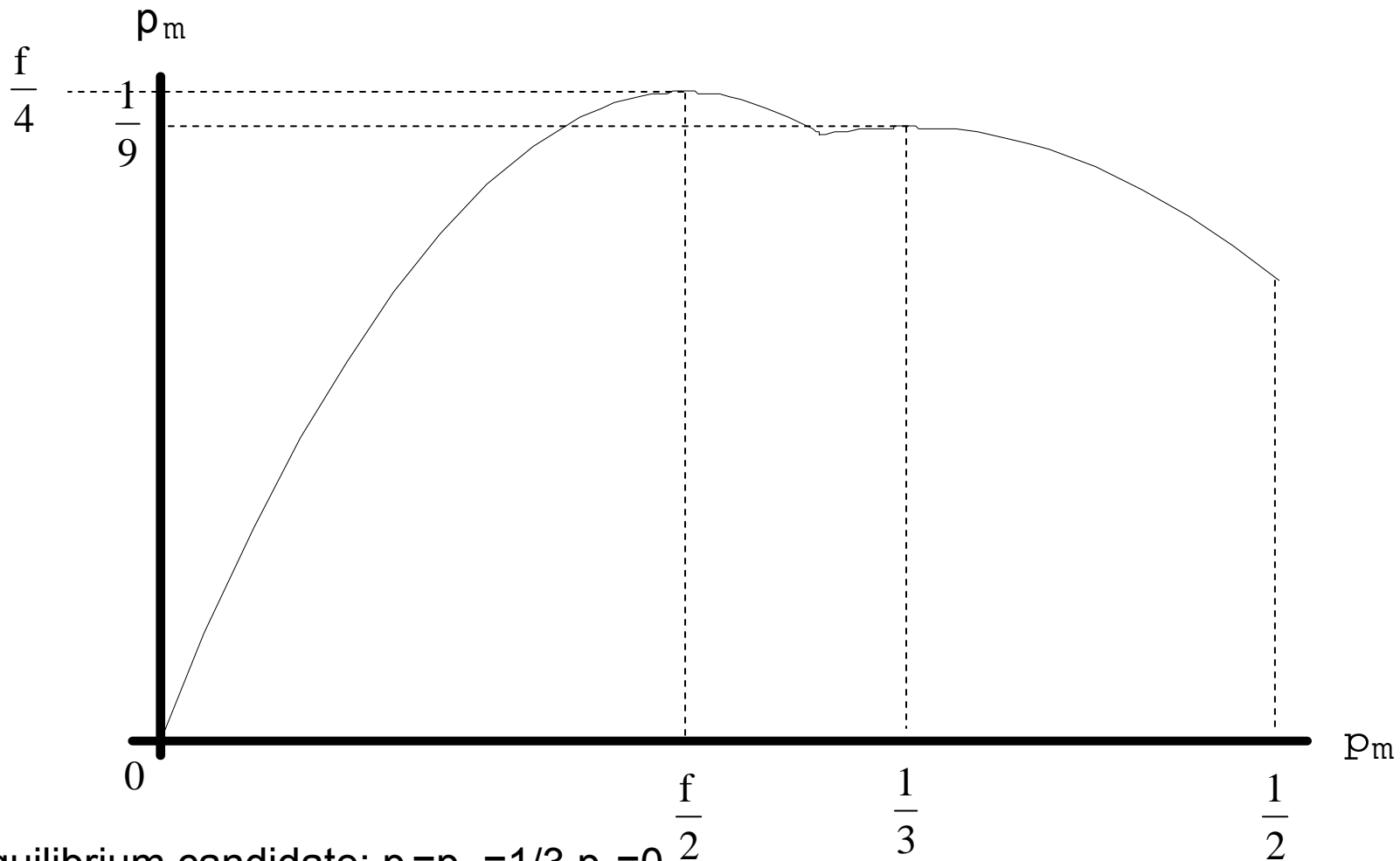
Intel's profit as a function of own price if MS stays put at the candidate price for a two-player equilibrium and AMD is out setting price equal to zero



Equilibrium candidate:  $p_i = p_m = 1/3$   $p_a = 0$

## AMD not active – Case 2 ( $4/9 < f < 1/2$ )

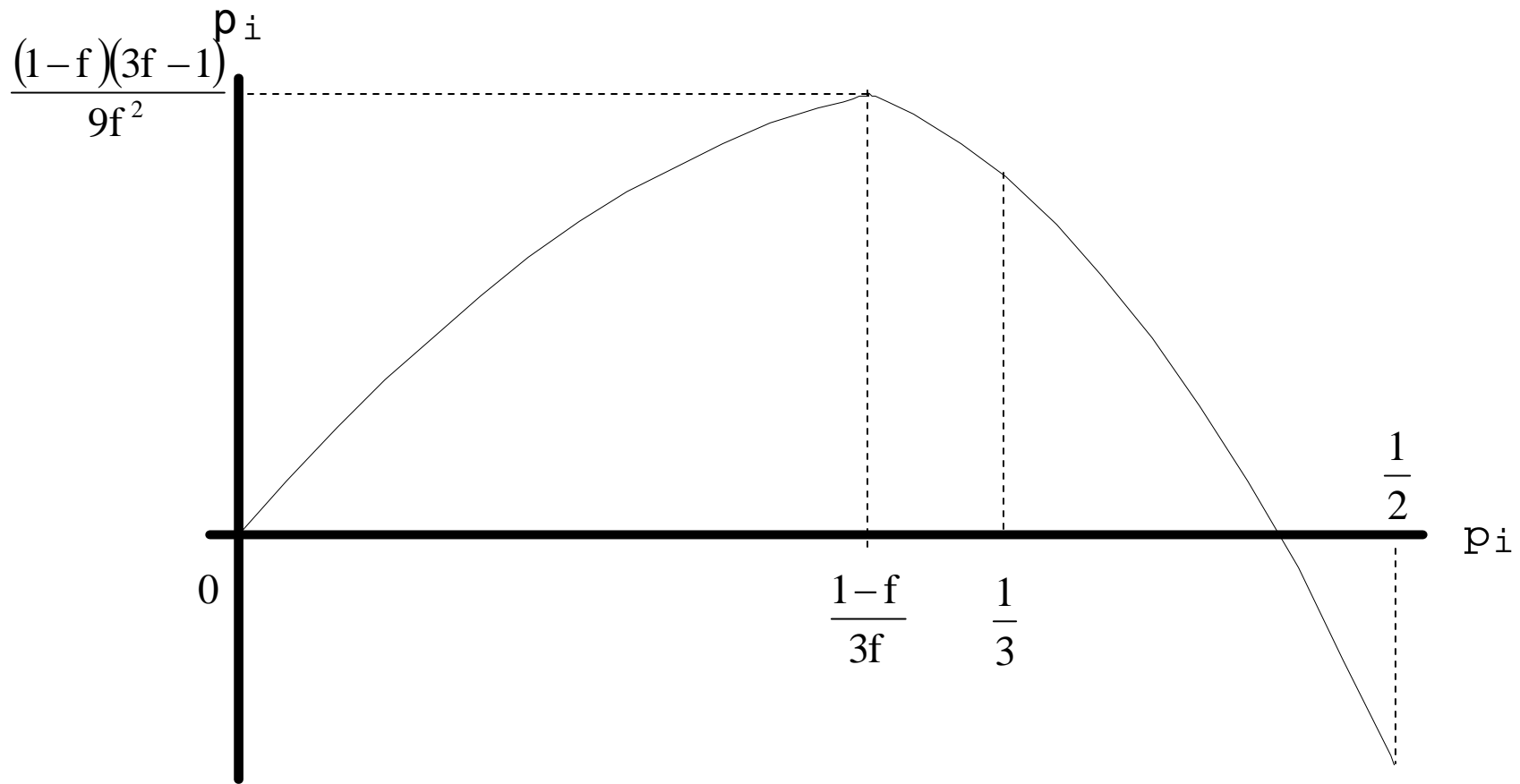
Microsoft's profit as a function of own price if Intel stays put at the candidate price for a two-player equilibrium and AMD is out setting price equal to zero



Equilibrium candidate:  $p_i = p_m = 1/3$   $p_a = 0$

### AMD not active – Case 3 ( $1/2 < f$ )

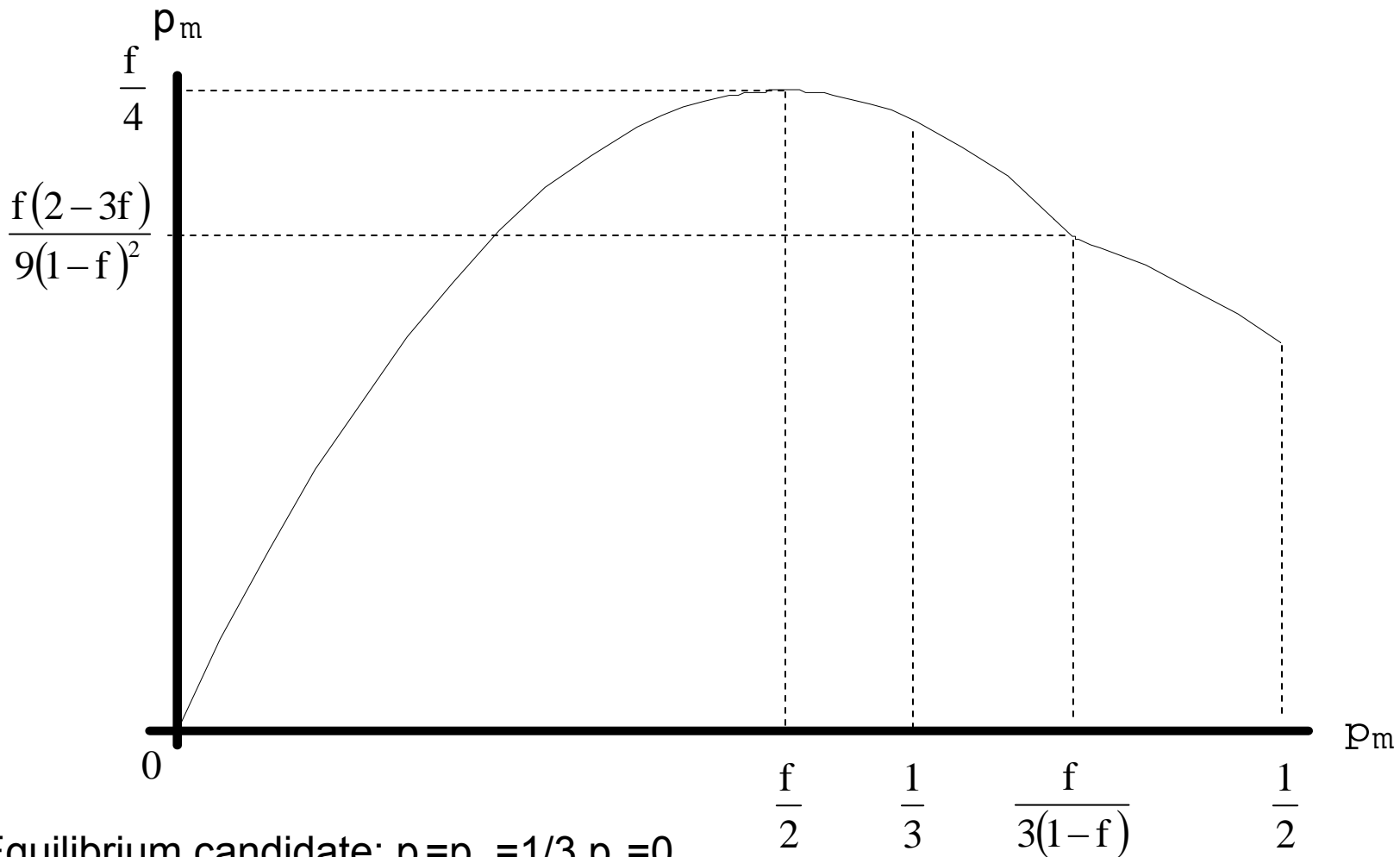
Intel's profit as a function of own price if MS stays put at the candidate price for a two-player equilibrium and AMD is out setting price equal to zero



Equilibrium candidate:  $p_i = p_m = 1/3$   $p_a = 0$

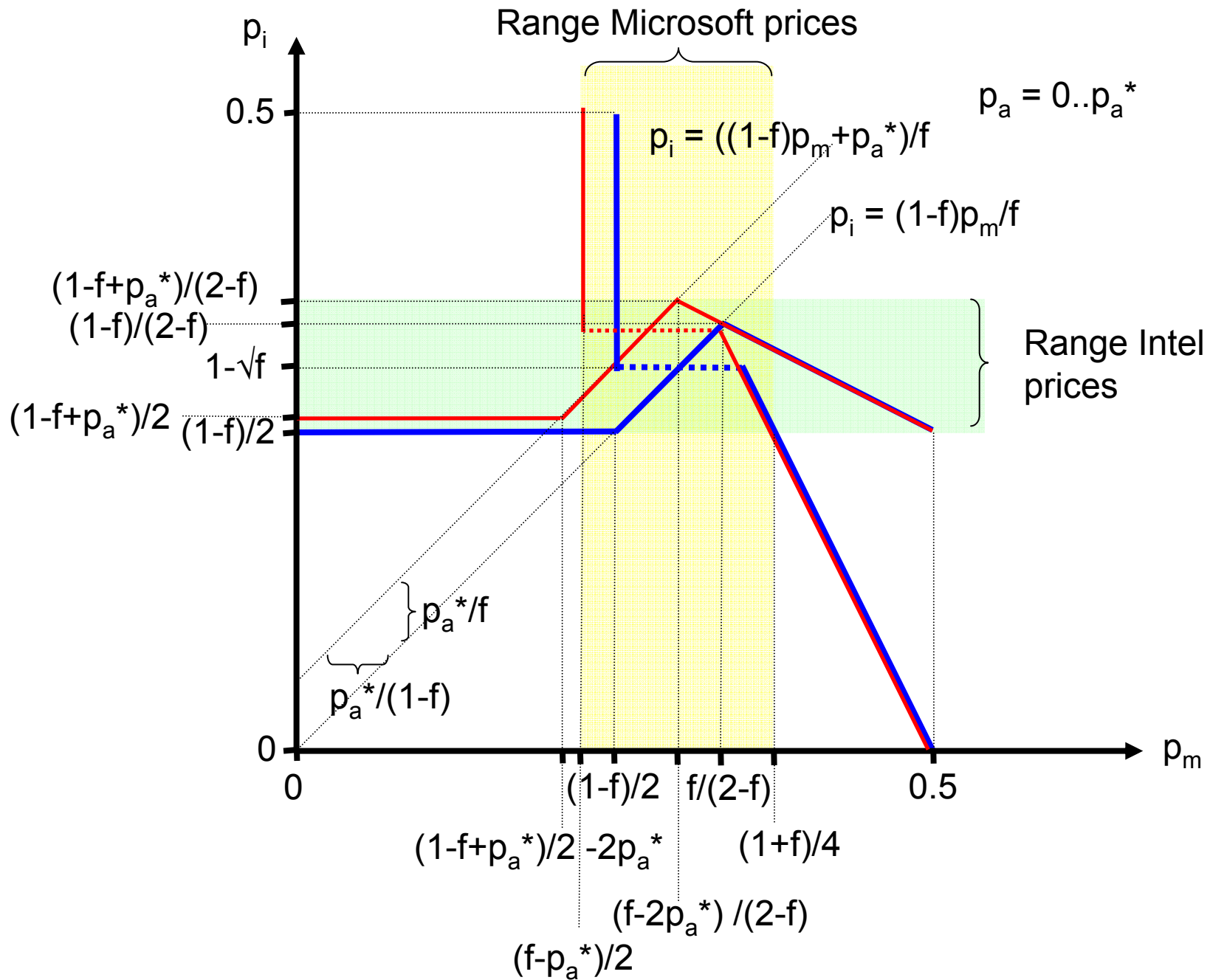
### AMD not active – Case 3 ( $1/2 < f$ )

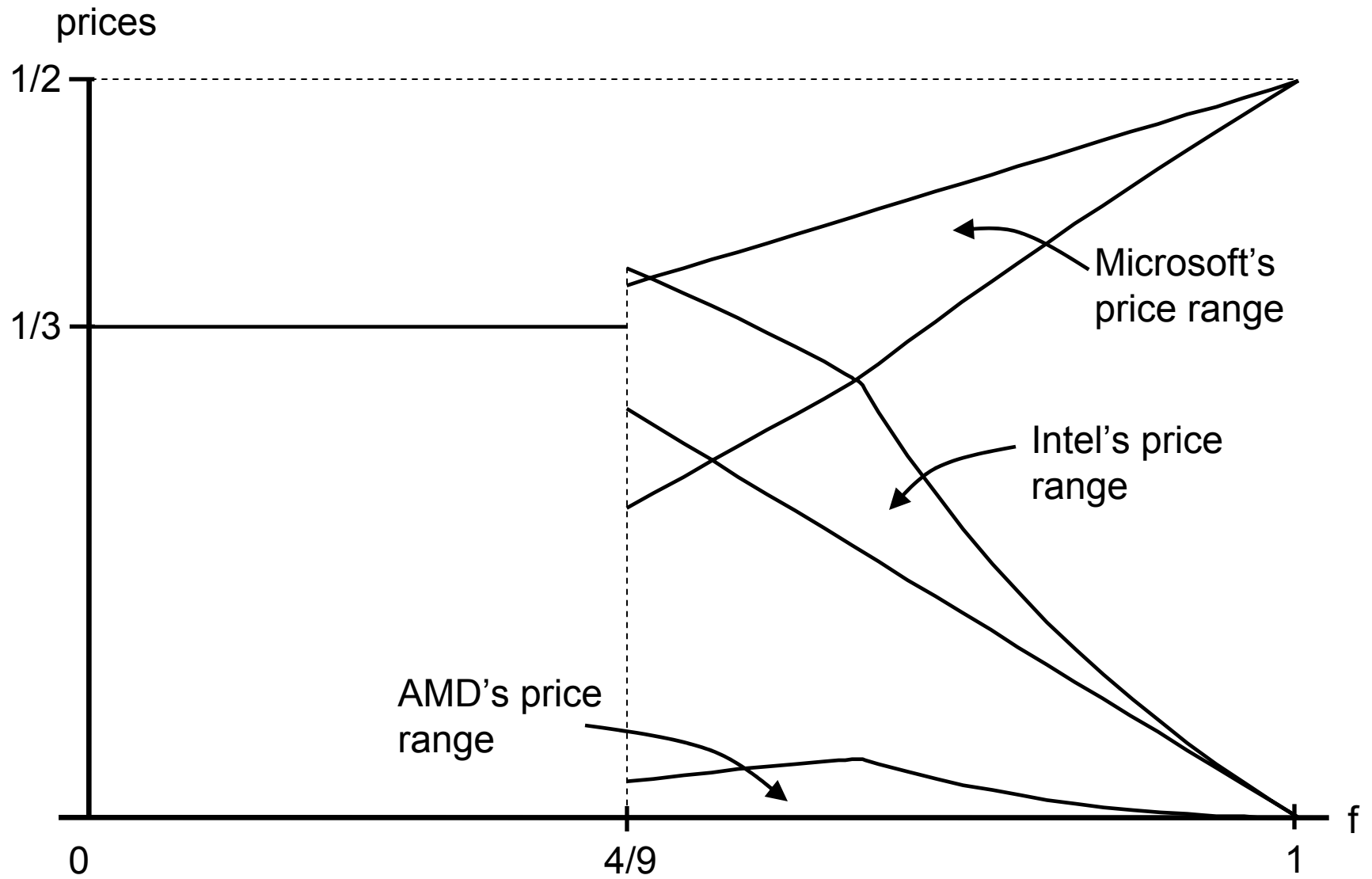
Microsoft's profit as a function of own price if Intel stays put at the candidate price for a two-player equilibrium and AMD is out setting price equal to zero



# Summary

- With zero costs, if  $4/9 < f < 1$ , there is no pure-strategy equilibrium
- Proof:
  - Result 1 says that there is no eq. with AMD active
  - Proof of Result 2 shows that  $(1/3, 1/3)$  is not an equilibrium (MS wants to deviate and bring AMD in) ■
- When  $f=1$ ,  $p_m=1/2$ ,  $p_i=p_a=0$  is an equilibrium





# Model with cost (I)

- We now introduce  $mc$ , positive and negative
  - Negative  $mc$ ? Microsoft enjoys negative marginal costs because in addition to making money from the flow of sale of new PCs it also anticipates future revenues from selling upgrades and applications to the installed base
    - Each new customer creates an annuity, reflected in the  $mc < 0$
  - Not for Intel and AMD

# Model with cost (II)

- Intel and AMD's mc:  $c_i = c_a = c \geq 0$ 
  - Best case for AMD
- Microsoft's mc:  $c_m \leq 0$
- Let  $z := c_m + c$ 
  - Notice that  $z$  may be positive or negative

# Model with cost (III)

- Profit functions:

Microsoft:  $\pi_m = (p_m - c_m) * q_m$

Intel:  $\pi_i = (p_i - c) * q_i$

AMD:  $\pi_a = (p_i - c) * q_a$

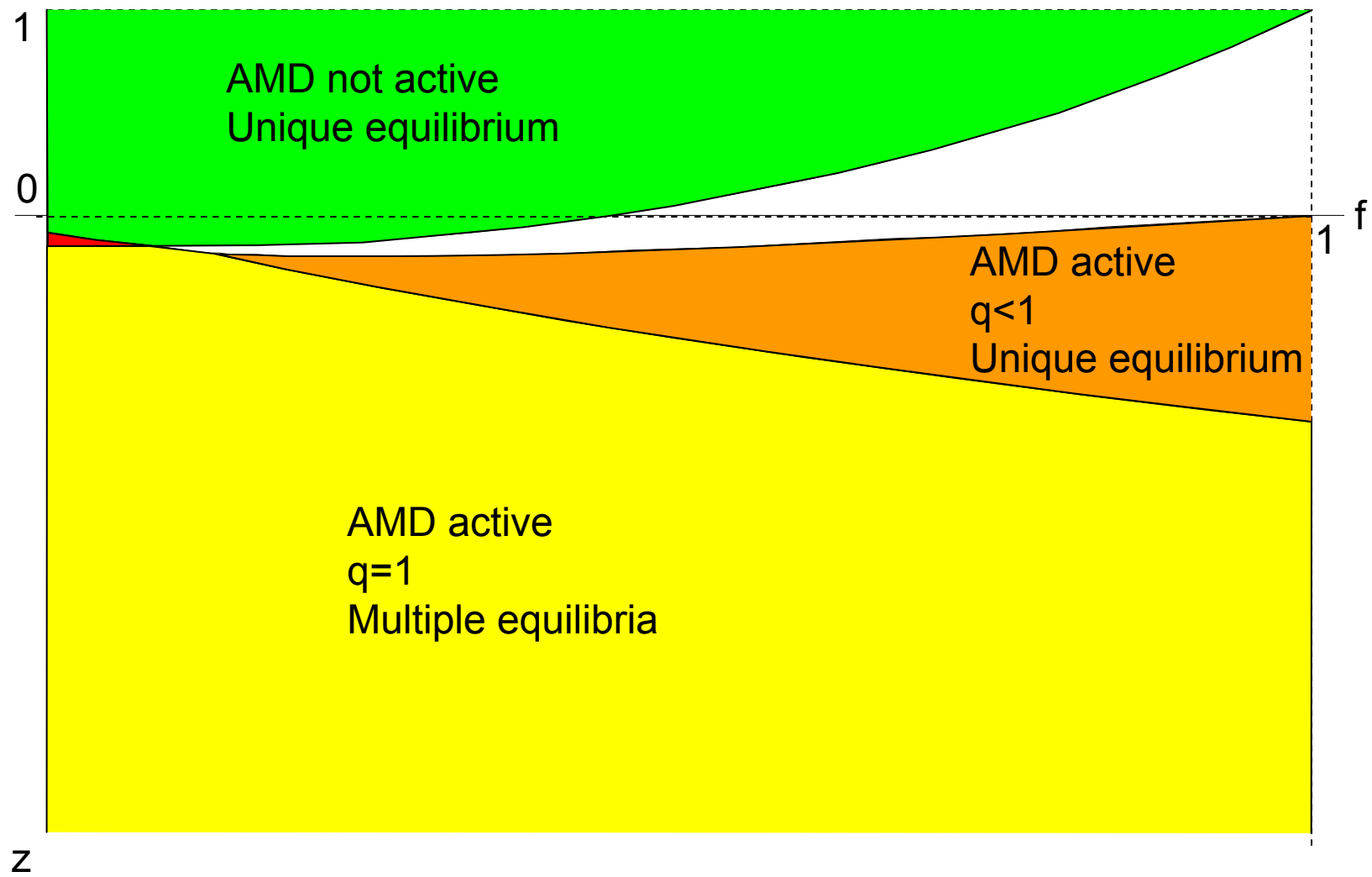
- Two-player world:

$$q_m = q_i = 1 - p_m - p_i$$

- Three-player world:

$$q_m = 1 - (p_a + p_m) / f \quad q_i = 1 - (p_i - p_a) / (1 - f)$$

$$q_a = (p_i - p_a) / (1 - f) - (p_a + p_m) / f$$



# Model with cost (III)

- Profit functions:

Microsoft:  $\pi_m = p_m * q_m - c_m * (1 - (1 - q_m)^2)$

Intel:  $\pi_i = (p_i - c) * q_i$

AMD:  $\pi_a = (p_i - c) * q_a$

- Two-player world:

$$q_m = q_i = 1 - p_m - p_i$$

- Three-player world:

$$q_m = 1 - (p_a + p_m) / f \quad q_i = 1 - (p_i - p_a) / (1 - f)$$

$$q_a = (p_i - p_a) / (1 - f) - (p_a + p_m) / f$$

# Negative mc cost function

$$\pi_m = p_m * q_m - c_m * (1 - (1 - q_m)^2)$$

$$d[-c_m * (1 - (1 - q_m)^2)] / dq_m = -2c_m * (1 - q_m) \geq 0$$

$$d^2[-c_m * (1 - (1 - q_m)^2)] / dq_m^2 = 2c_m < 0$$

- When  $q=0$ , no extra revenue
- Incremental revenue falls when marginal customer has lower valuation

# Monopoly Complement Solution

- At  $f=0.1$ ,  $c=0$  we have stable monopoly complement solutions at both  $c_m=-0.185$  and  $c_m=-0.18$ . (In both cases, AMD is not active.)

$f=0.1$ ,  $c_m = -0.185$ ,  $c=0 \rightarrow q_m=0.406$ ;  $\pi_m = 0.196$   
 $p_m = 0.187$ ;  $p_i = 0.406$ ;  $p_a = \text{Not Active}$

$f=0.1$ ,  $c_m = -0.18$ ,  $c=0 \rightarrow q_m=0.404$ ;  $\pi_m = 0.193$   
 $p_m = 0.190$ ;  $p_i = 0.404$ ;  $p_a = \text{Not Active}$

# Duopoly Complement Solution

- At  $f=0.1$ ,  $c=0$  we have a stable duopoly complement solution at  $c_m=-0.185$ . At  $c_m=-0.18$ , there is no stable solution

$$f=0.1, c_m = -0.185, c=0 \rightarrow q_m=0.782; \pi_m=0.1743$$

$$p_m = -0.0024; p_i = 0.4621; p_a = 0.0242$$

$$f=0.1, c_m = -0.18, c=0 \rightarrow q_m=0.778; \pi_m=0.169$$

$$p_m = -0.0017; p_i = 0.4619; p_a = 0.0238$$

# Duopoly Complement Solution

- At  $f=0.1$ ,  $c=0$  we have a stable duopoly complement solution at  $c_m=-0.185$ . At  $c_m=-0.18$ , there is no stable solution

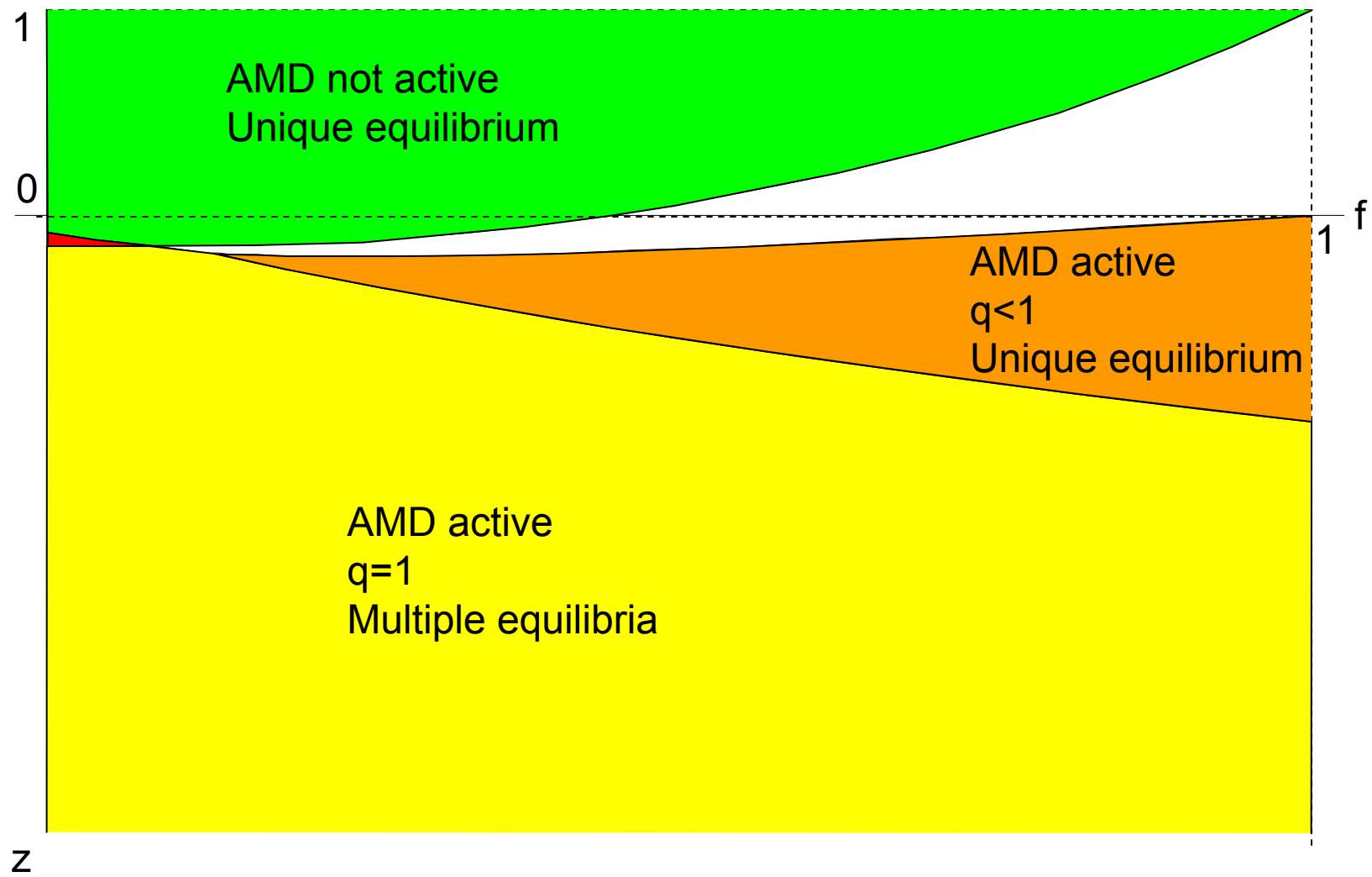
$$f=0.1, c_m = -0.185, c=0 \rightarrow q_m=0.782; \pi_m=0.1743$$
$$p_m = -0.0024; p_i = 0.4621; p_a = 0.0242$$

~~$$f=0.1, c_m = -0.18, c=0 \rightarrow q_m=0.778; \pi_m=0.169$$
$$p_m = -0.0017; p_i = 0.4619; p_a = 0.0238$$~~

# Summary

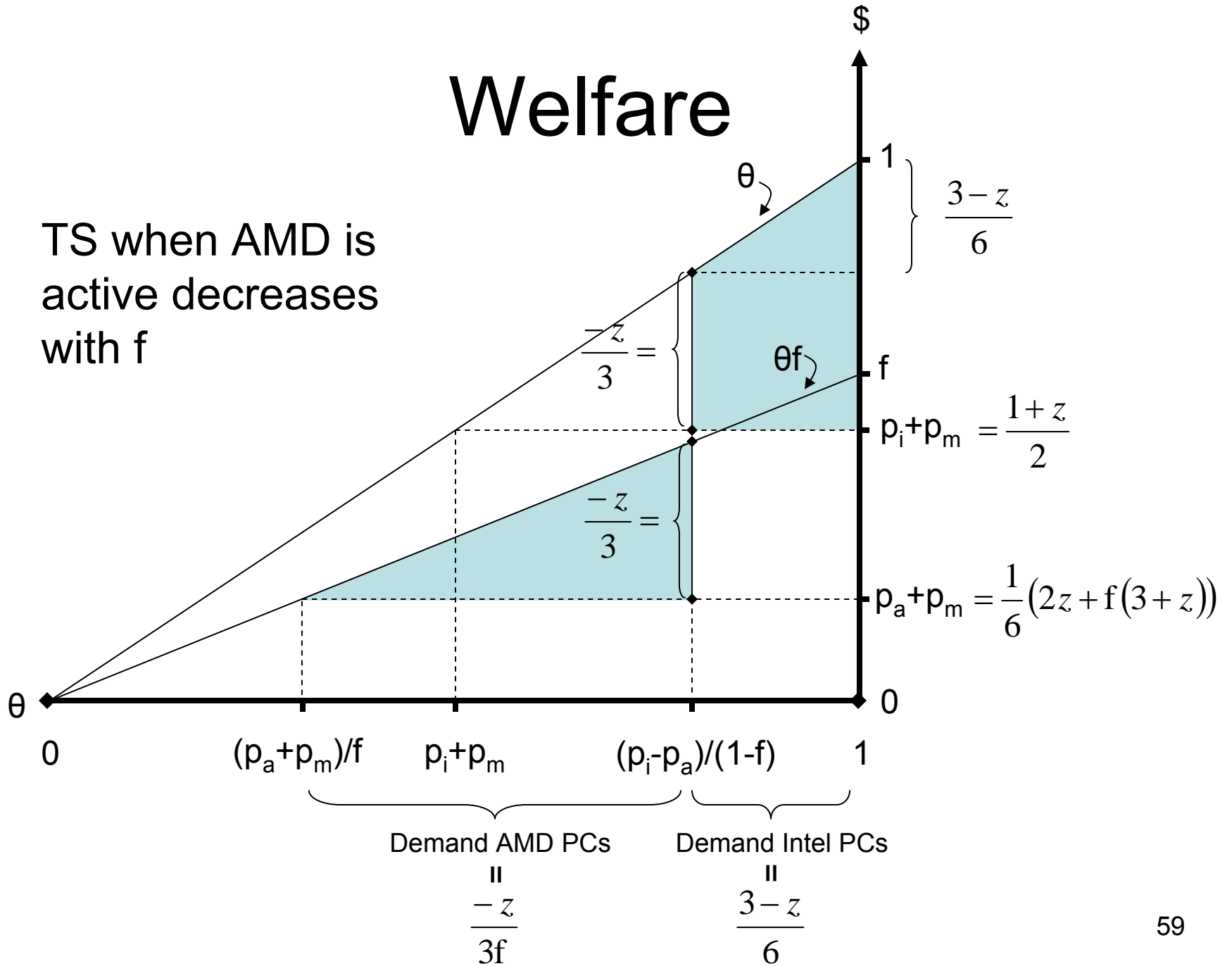
	<u>Monopoly Complement</u>	<u>Duopoly Complement</u>
$c_m = -0.185$	$\pi_m = 0.196$	$\pi_m = 0.173$
$c_m = -0.18$	$\pi_m = 0.193$	<del><math>\pi_m = 0.169</math></del>

1. Multiplicity of equilibria ... though not for all parameter values
2. May make more against Intel alone than against Intel + AMD!
3. Begin at 3-world with  $c_m = -0.185$ , incentive to deteriorate cost position and move to 2-world
4. May not be typical. We don't know



# Welfare

TS when AMD is active decreases with  $f$



# Conclusions

- *Literature*. First step towards more general model of competing complements. Even a small departure from standard model leads to surprisingly complicated interactions and non-existence of equilibria
- *Managers*. One way to break 50:50 is by encouraging competition in complement space
  - A little bit of competition is not good enough
- *Regulators*. More competition within complements is bad for welfare
  - Should MS be allowed to ‘help’ AMD?