Electricity Pricing

Lectures 3-4 in EG2050 System Planning

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Course objectives

To pass the course, the students should show that they are able to

- perform rough estimations of electricity prices.

To receive a higher grade (A, B, C, D) the students should also show that they are able to

- identify factors that have a large importance for the electricity pricing, and to indicate how these factors affect for example producers and consumers.

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Ideal Pricing

What price would we have in an ideal market?

- Assume a set, $\boldsymbol{G}$, of producers, where each producer, g, has to decide its production, G_g.
- Assume a set, $\boldsymbol{C}$, of consumers, where each consumer, c, has to decide its consumption, D_c.
- Ignore transaction costs.

Price-taking producer (1/2)

Definition: A price-taking producer has such a small market share that the market price, λ, is not affected by the choice of production level, G_g.

The profit is equal to

$$PS_g = \lambda G_g - C_{G_g}(G_g),$$

where

PS_g represents the surplus of producer g

$C_{G_g}(G_g)$ represents the cost to produce G_g

Price-taking producer (2/2)

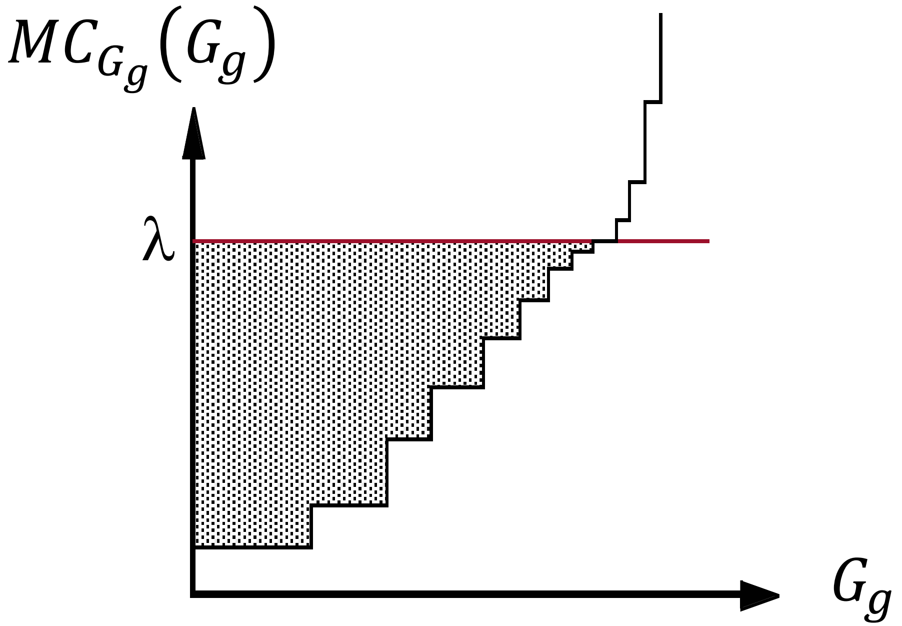
Which production level maximizes profits?

Study the marginal cost curve, i.e., the variable costs

$$MC_{G_g}(G_g) = \frac{dC_{G_g}(G_g)}{dG_g}$$

=> choose G_g such that

$$MC_{G_g}(G_g) = \lambda.$$



Price-taking Consumer (1/2)

Definition: A price-taking consumer has such a small market share that the market price, λ, is not affected by the choice of consumption level, D_c.

The profit is equal to

$$CS_c = B_{D_c}(D_c) - \lambda D_c,$$

where

CS_c represents the surplus of customer c,

$B_{D_c}(D_c)$ represents the benefit of consuming D_c.

Price-taking Consumer (2/2)

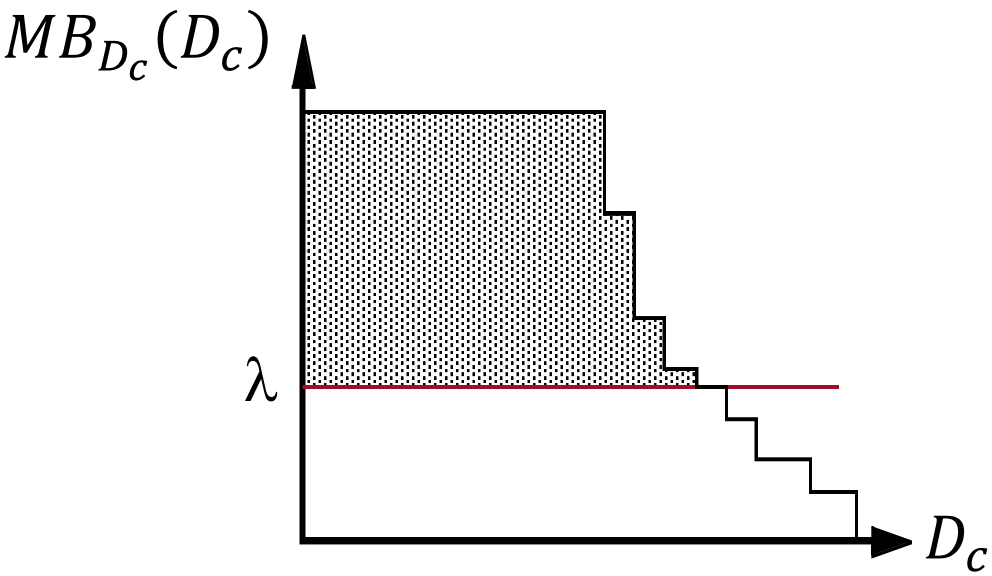
Which consumption level maximizes profits?

Study the marginal benefit curve, i.e., the willingness to pay

$$MB_{D_c}(D_c) = \frac{dB_{D_c}(D_c)}{dD_c}$$

=> choose D_c such that

$$MB_{D_c}(D_c) = \lambda.$$



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Benefit to the society

- Producers will increase their production until the marginal production cost is equal to the market price.
- Consumers will increase their consumption until the marginal benefit is equal to the market price.

Is this behavior beneficial to the society?

=> Study the total surplus.

Total surplus (1/2)

Definition: The total surplus, TS is given by

$$TS = \sum_c CS_c + \sum_g PS_g = \cdots = \sum_c B_{D_c}(D_c) + \sum_g C_{G_g}(G_g)$$

Note! The total surplus is not a perfect measure of the benefit to the society.

It presumes that all benefits and costs can be assigned monetary values (externalities)

Total surplus (2/2)

- Combine all consumers marginal benefit functions into a demand curve, MB.
- Combine all producers marginal cost functions into a supply curve, MC.

The total surplus is maximized if

$$MB = MC = \lambda.$$

- MB denotes Marginal Benefit, whereas
- MC denotes Marginal Cost.

Market price

- In an ideal market (perfect competition, perfect information, etc.) there will be a market price which maximizes both the total surplus and each individual surplus of all the producers and consumers.
- The market price is set by the intersection of the supply curve and the demand curve, i.e., marginal production costs and willingness to pay.

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Simple Price Model

Assume:

- Perfect competition
- Perfect information
- No capacity limitations
- No transmission limitations
- No reservoir limitations
- Price insensitive load

=> Mean electricity price can be estimated by studying the supply curve on an annual basis.

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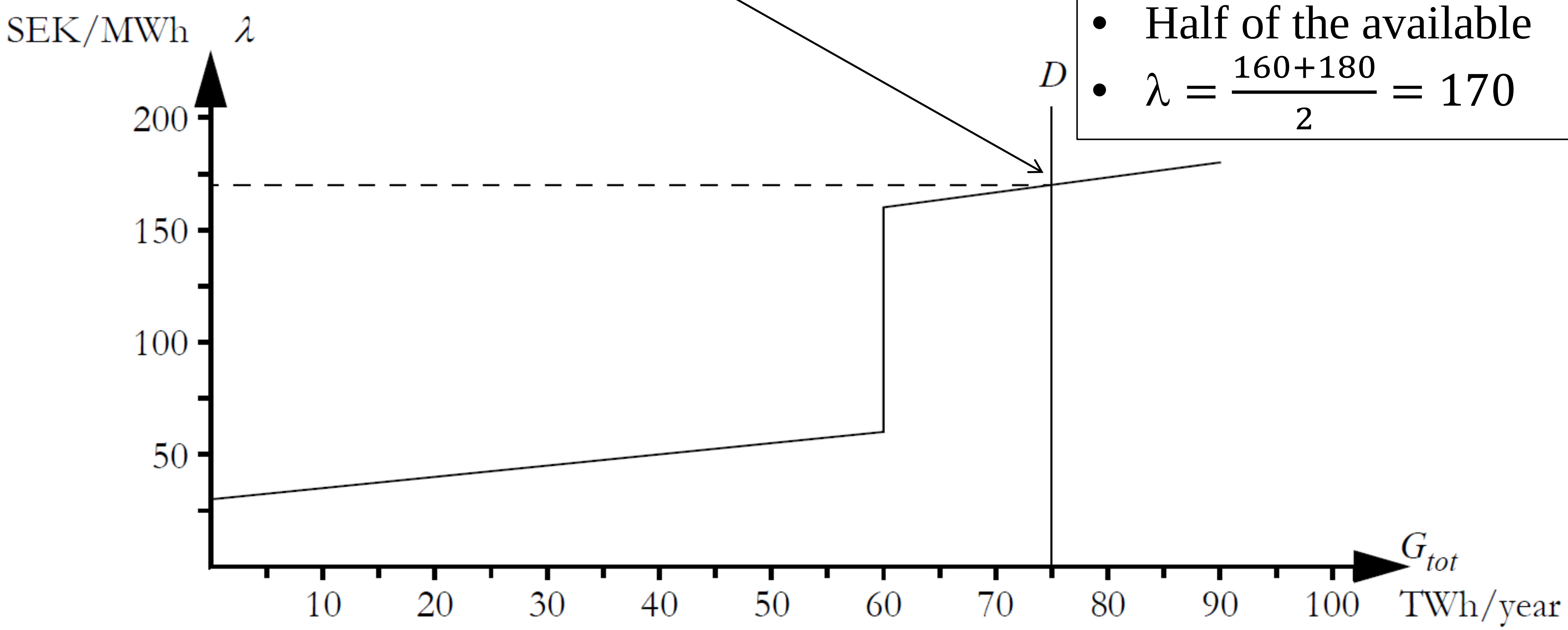
Example 3.1 – Problem

- Load 75 TWh/year
- Hydro power
  - 60 TWh/year
  - 30-60 SEK/MWh
- Coal condensing
  - 30 TWh/year
  - 160-180 SEK/MWh
- What will the electricity price be?
- Calculate the difference between variable operation cost and total income of the power producers! (total producers' surplus)

Example 3.1 – Solution (1/2)

λ = 170 SEK/MWh

- $75 > 60 \Rightarrow$ thermal
- 15 TWh thermal needed
- Half of the available
- $\lambda = \frac{160+180}{2} = 170$



Example 3.1 – Solution (2/2)

- Total variable operation cost
- $PC = 60\frac{30+60}{2} + 15\frac{160+170}{2} = 5175 \text{ MSEK}$
- whereas the income
- $PV = 75 \cdot 170 = 12750 \text{ MSEK}$
- and, thus the total producers' surplus is
- $12750 - 5175 = 7575 \text{ MSEK}$

Exercise 3.6 (p 32) – Problem (1/5)

- Table 3.2 shows
  - the available generation resources,
  - marginal generation costs,
  - and annual consumption in the Nordic countries during year 2000.
- The operation costs are assumed to be linear within the stated intervals.
- Assume
  - Perfect competition
  - Perfect information
  - *Continues ...*

Exercise 3.6 (p 32) – Problem (2/5)

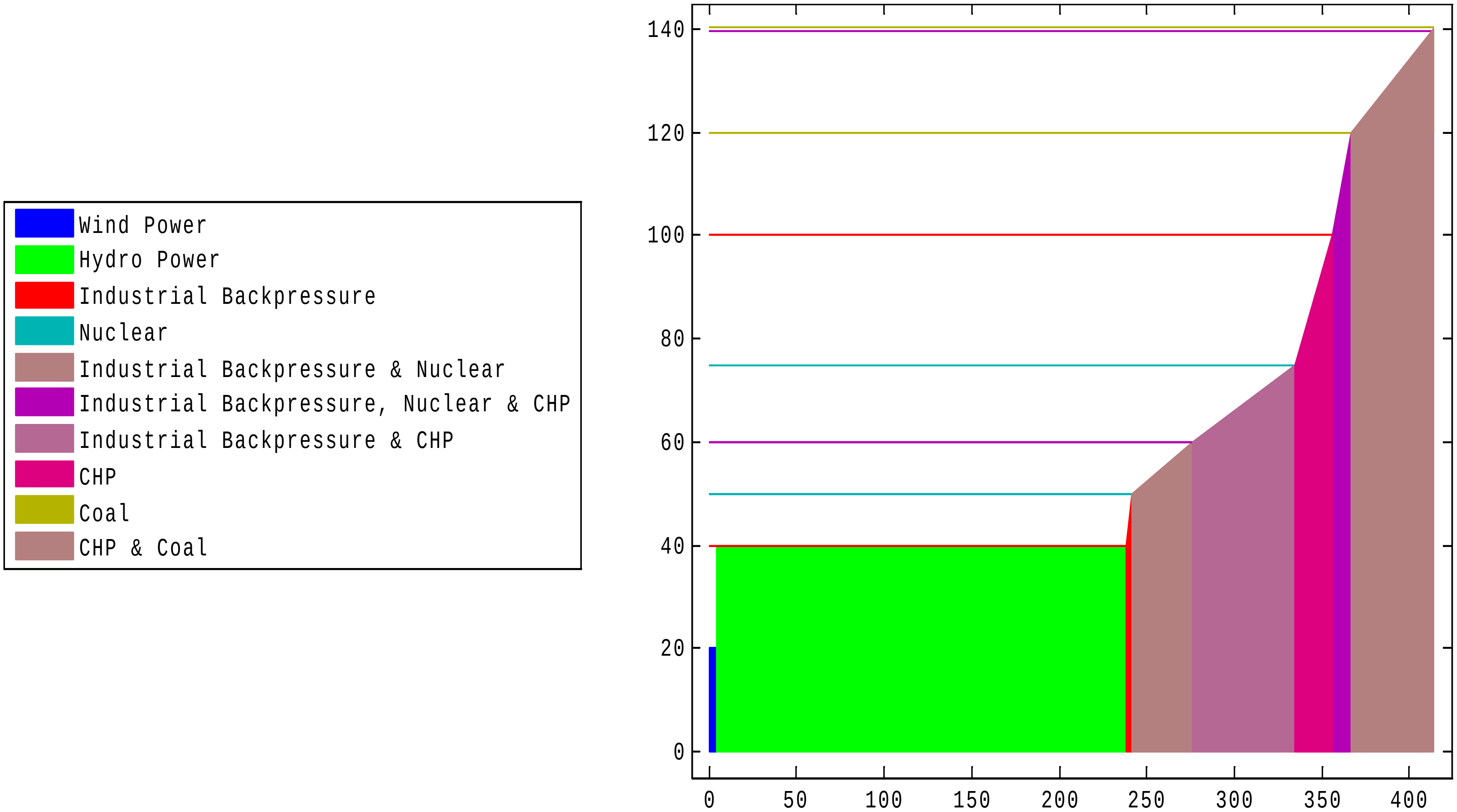
- Assume
  - *Continued …*
  - That there a neither any
    - Capacity
    - Transmission, nor
    - Reservoir limitations
- Trade
  - Finland imports 4 TWh from Russia
  - Denmark exports 5 TWh to Germany
  - Sweden exports
    - 0.5 TWh to Germany and
    - 0.5 TWh to Poland

Exercise 3.6 (p 32) – Problem (3/5)

Table 3.2 Available generation resources and annual consumption.

Power source	Production capability [TWh/year]				Cost [SEK/MWh]
	Sweden	Norway	Finland	Denmark	
Hydro power	78	142	14	-	40
Wind power	0.5	0	0	4	20
Nuclear power	55	-	21.5	-	50–75
Industrial backpressure	5	-	13	2	40–100
Comb. heat and power	5	-	13	24	60–140
Coal condensing	-	-	13	24	120–140
Consumption	146	124	79	35	

Exercise 3.6 (p 32) – Problem (4/5)



Exercise 3.6 (p 32) – Problem (5/5)

- Estimate the electricity price
- Estimate the trading between the Nordic countries
- How would the electricity price be affected if the reservoir sizes are reduced such that they are filled on July 31?
  - Everything else is kept constant in the problem
  - Describe the trend orally, no numerical values or computations needed

Exercise 3.6 (p 32) – Solution (1/3)

- Net export: $1 - 4 + 5 = 2$
- Total consumption in the Nordic countries: $146 + 124 + 79 + 35 + 2\,(\text{net export}) = 386$.
- Assume that all hydro, wind, nuclear, and industrial back-pressure is utilized =>
- Total production: $78 + 142 + 14 + 0.5 + 4 + 55 + 21.5 + 5 + 13 + 2 = 335$, which is not enough,
- 51 TWh more needed.
- Assume a price between 100 and 120 SEK/MWh:
  - Combined heat and power (CHP), capacity $5 + 13 + 24 = 42 < 51$
  - Coal condensing needed!

Exercise 3.6 (p 32) – Solution (2/3)

- Assume a price between 100 and 140 SEK/MWh:
- $\frac{\lambda - 60}{140 - 60} \cdot 42 + \frac{\lambda - 120}{140 - 120} \cdot 37 = 51 \Rightarrow \lambda = \frac{2436}{19} \approx 128.21 \text{ SEK/MWh}$
- Error-check: Is the price within the assumed range?
- Answer: 128.21 SEK/MWh
- Shares of total possible production:
  - CHP: $\frac{\lambda - 60}{140 - 60} = \frac{51}{79} \approx 0.853$
  - Coal: $\frac{\lambda - 120}{140 - 120} = \frac{39}{95} \approx 0.411$
- Swedish net production: $78 + 0.5 + 55 + 5 + 5 \cdot 0.853 - 146 - 1 \approx -4.2$ => Imports 4.2 TWh

Exercise 3.6 (p 32) – Solution (3/3)

- Norwegian net production: $142 - 124 = 18$ => Exports 18 TWh
- Finnish net production: $14 + 21.5 + 13 + 13 \cdot 0.853 + 13 \cdot 0.411 - 79 + 4 \approx -10.1$ => Imports 10.1 TWh
- Danish net production: $4 + 2 + 24 \cdot 0.853 + 24 \cdot 0.411 - 35 - 5 \approx -3.7$ => Imports 3.7 TWh
- Check: Sums to zero!, CHP preferred!
- Reservoir sizes such that they are filled on July 31
  - It is better to use the water rather than to spill it
  - This reduces the prices before July 31
  - And increases the prices after July 31, since there will be a shortage of water then

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Example 3.3 – Problem (1/2)

- Load:
  - 1 January - 30 June: 35 TWh
  - 1 July - 31 December: 40 TWh
- Coal condensing 30 TWh/year.
  - evenly distributed over the year
  - 160-180 SEK/MWh
- Hydro power
  - Similar to Example 3.1
  - 30-60 SEK/MWh
  - *Continues ...*

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Example 3.3 – Problem (2/2)

- Hydro power
  - *Continued ...*
  - Reservoir capacity: 18 TWh
  - Reservoir contents:
    - 1 January, 00:00: 0 TWh
    - 1 July, 00:00: 18 TWh
    - 31 December, 23:59: 0 TWh
  - Inflow:
    - 1 January - 30 June: 50 TWh
    - 1 July - 31 December: 10 TWh
- Determine the electricity price during the year

Example 3.3 – Solution #1 (1/3)

- First six months:
  - Hydro potential: $50 - 18 = 32$ TWh.
  - Load: 35 TWh => Fully utilized => $\lambda > 60$ SEK/MWh.
  - Coal condensing potential: 15 TWh.
  - 3 TWh coal energy needed => 20% utilized => $\lambda = 0.8 \cdot 160 + 0.2 \cdot 180 = 164$ SEK/MWh.
- Last six months:
  - Hydro potential: $10 + 18 = 28$ TWh.
  - Load: 40 TWh => Fully utilized => $\lambda > 60$ SEK/MWh.
  - Coal condensing potential: 15 TWh.
  - 12 TWh coal energy needed => 80% utilized => $\lambda = 0.2 \cdot 160 + 0.8 \cdot 180 = 176$ SEK/MWh.

Example 3.3 – Solution #2 (2/3)

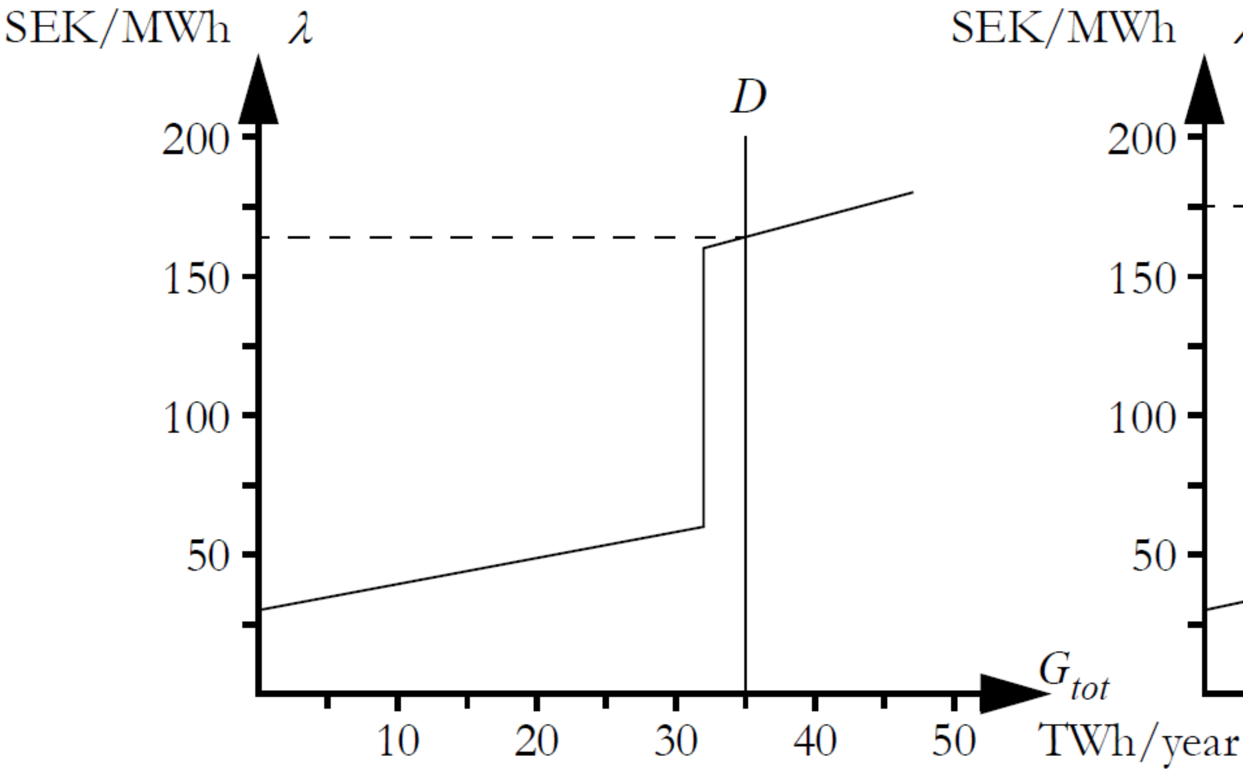


Figure 3.4 Supply and demand during the first six months.

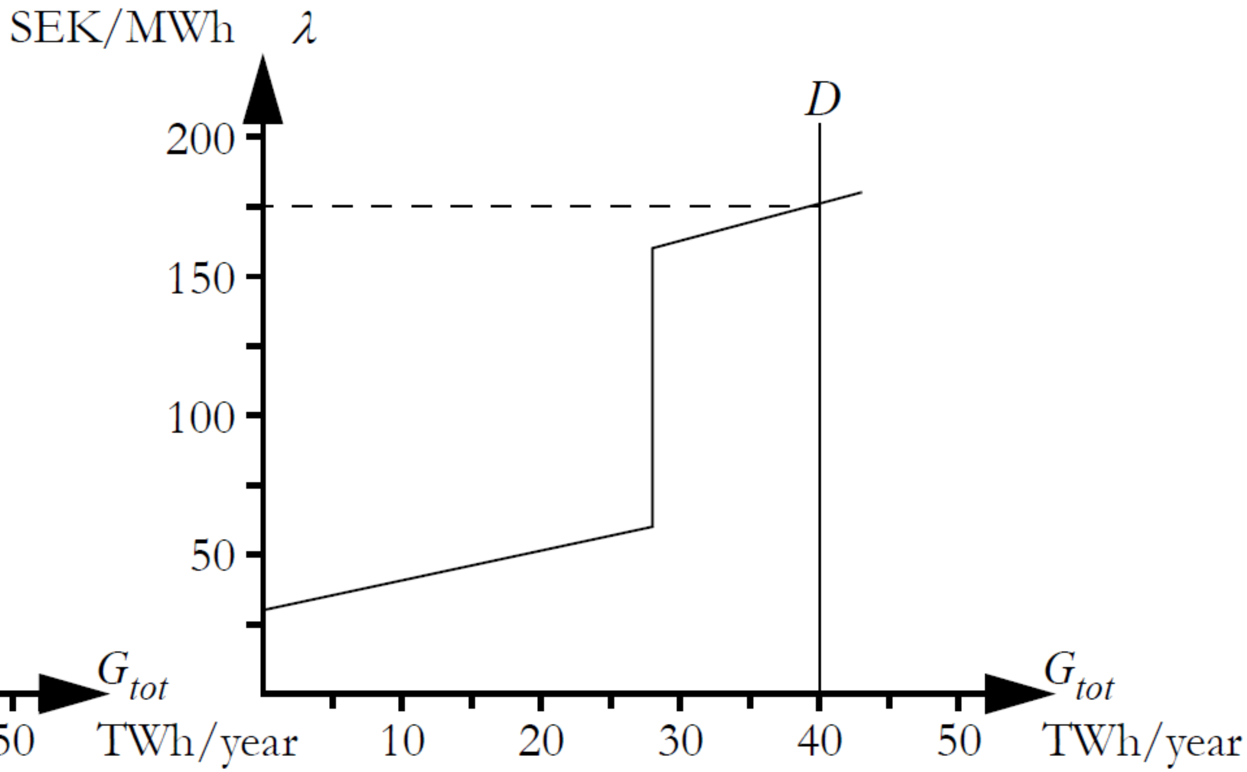


Figure 3.5 Supply and demand during the last six months.

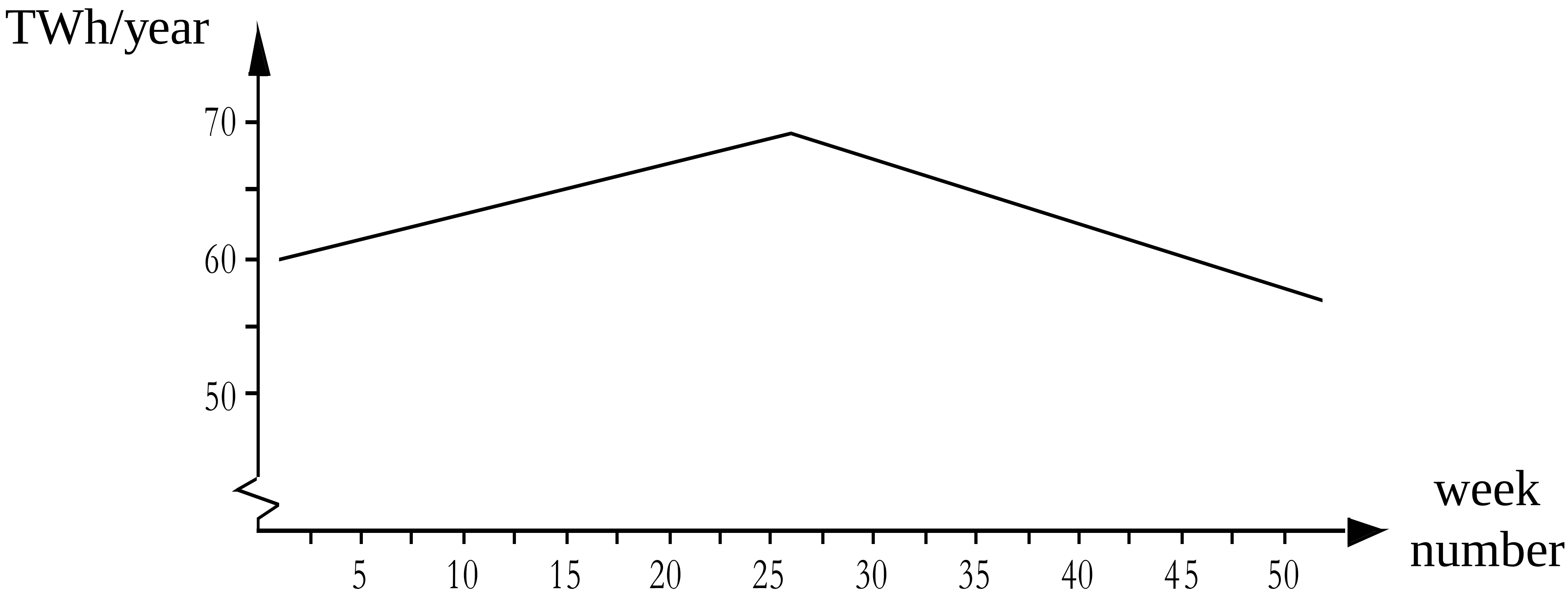
Example 3.3 – Solution #2 (3/3)

- First six months:
  - $32 + 15\left(\frac{\lambda - 160}{180 - 160}\right) = 35$
  - $\lambda = 164$
- Last six months:
  - $28 + 15\left(\frac{\lambda - 160}{180 - 160}\right) = 40$
  - $\lambda = 176$

Example 3.4 - Problem

How will the price develop during the studied year?

The same system as in Example 3.1, but the inflow forecast for the next 12 months varies as follows:



Example 3.4 – Solution #1 (1/4)

- Strategy:
  - Find the brake point of the piecewise linear function
  - Draw the lines between these points
- Week 1: Same as in Example 3.1
  - $\lambda = 170$ SEK/MWh
- Week 26:
  - Hydro potential: 69 TWh.
  - Load is till 75 TWh
  - Fully utilized => $\lambda > 60$ SEK/MWh.
  - Coal condensing potential: 30 TWh.
  - 6 TWh coal energy needed
  - 20% utilized $\lambda = 0.8 \cdot 160 + 0.2 \cdot 180 = 164$ SEK/MWh.

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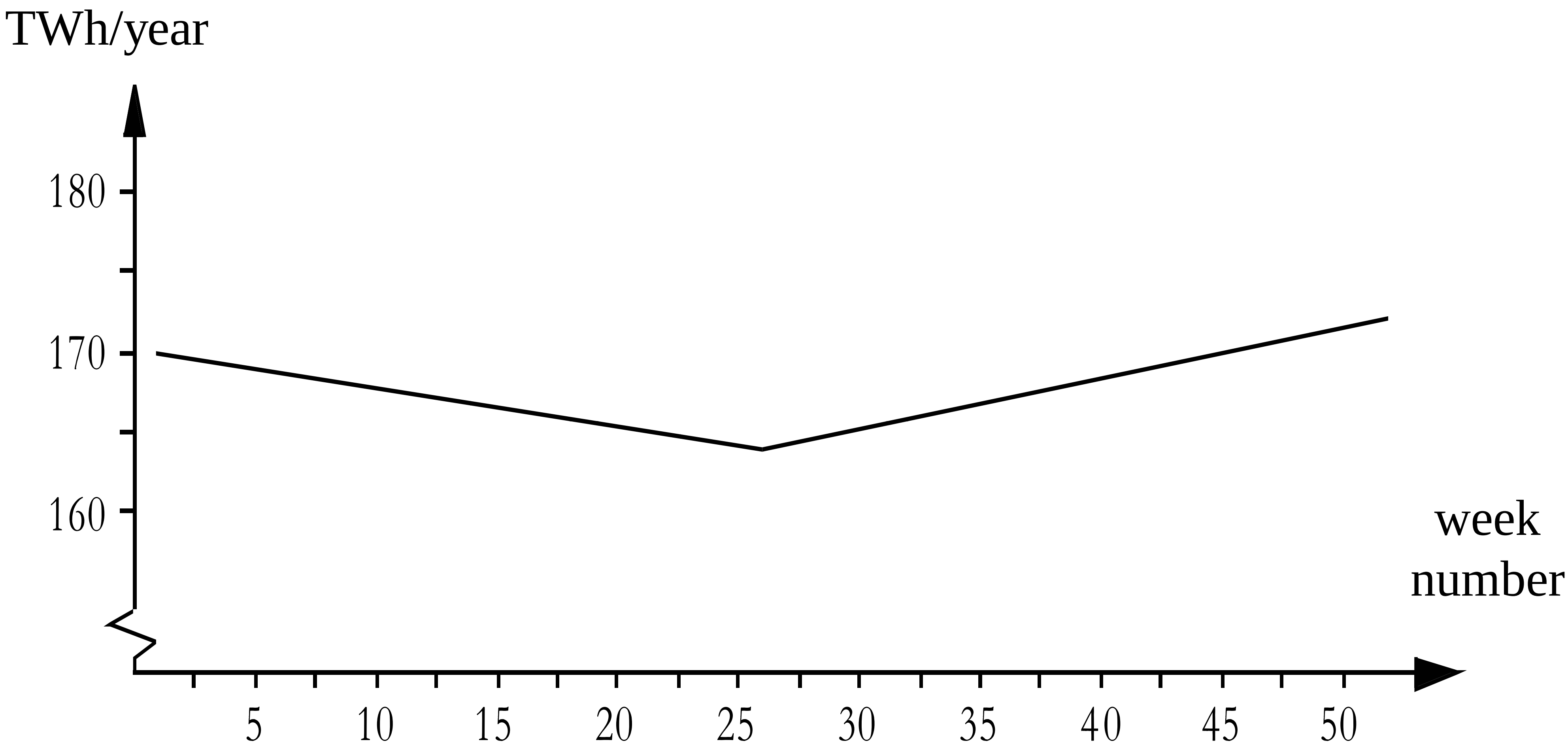
Example 3.4 – Solution #1 (2/4)

- Week 52:
  - Hydro potential: 57 TWh.
  - Load is till 75 TWh
  - Fully utilized => $\lambda > 60$ SEK/MWh.
  - Coal condensing potential: 30 TWh.
  - 18 TWh coal energy needed
  - 60% utilized => $\lambda = 0.4 \cdot 160 + 0.6 \cdot 180 = 172$ SEK/MWh.

Example 3.4 – Solution #1 (3/4)

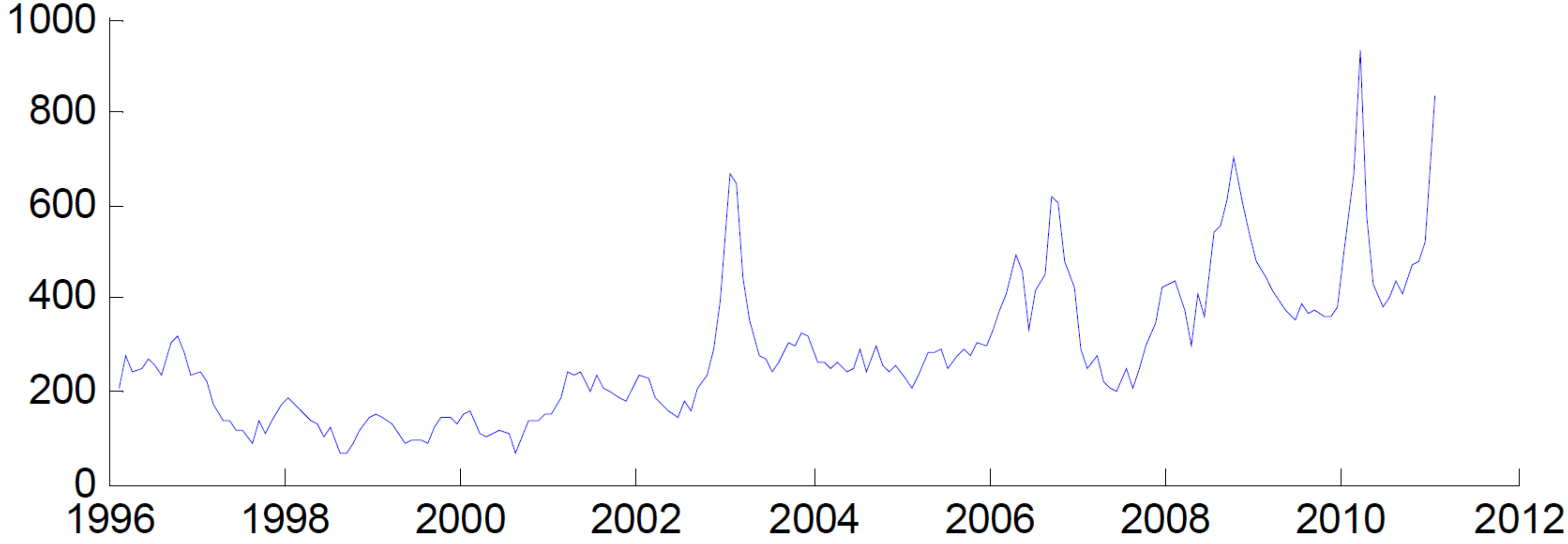


Example 3.4 – Solution #2 (4/4)

- Strategy:
  - Demand of 75 TWh
  - Hydro power will never suffice by its own
  - Coal needed, the amount needed is a linear function of forecasted hydro potential
  - Price varies linearly with marginal coal price
- $\lambda = 160 + \left(\frac{180-160}{30}\right)(75 - V)$
  - Where, $(75 - V)$ represents the remaining demand on coal
  - $75 - V \leq 30 \Rightarrow V \geq 45$, where 30 denotes the coal capacity
  - $75 - V \geq 0 \Rightarrow V \leq 75$, which ensures that the needed coal energy is nonnegative
  - Thus: holds as long $45 \leq V \leq 75$

Nord Pool Prices (1/2)

Average electricity price [SEK/MWh] per month in Nord Pool price area Stockholm



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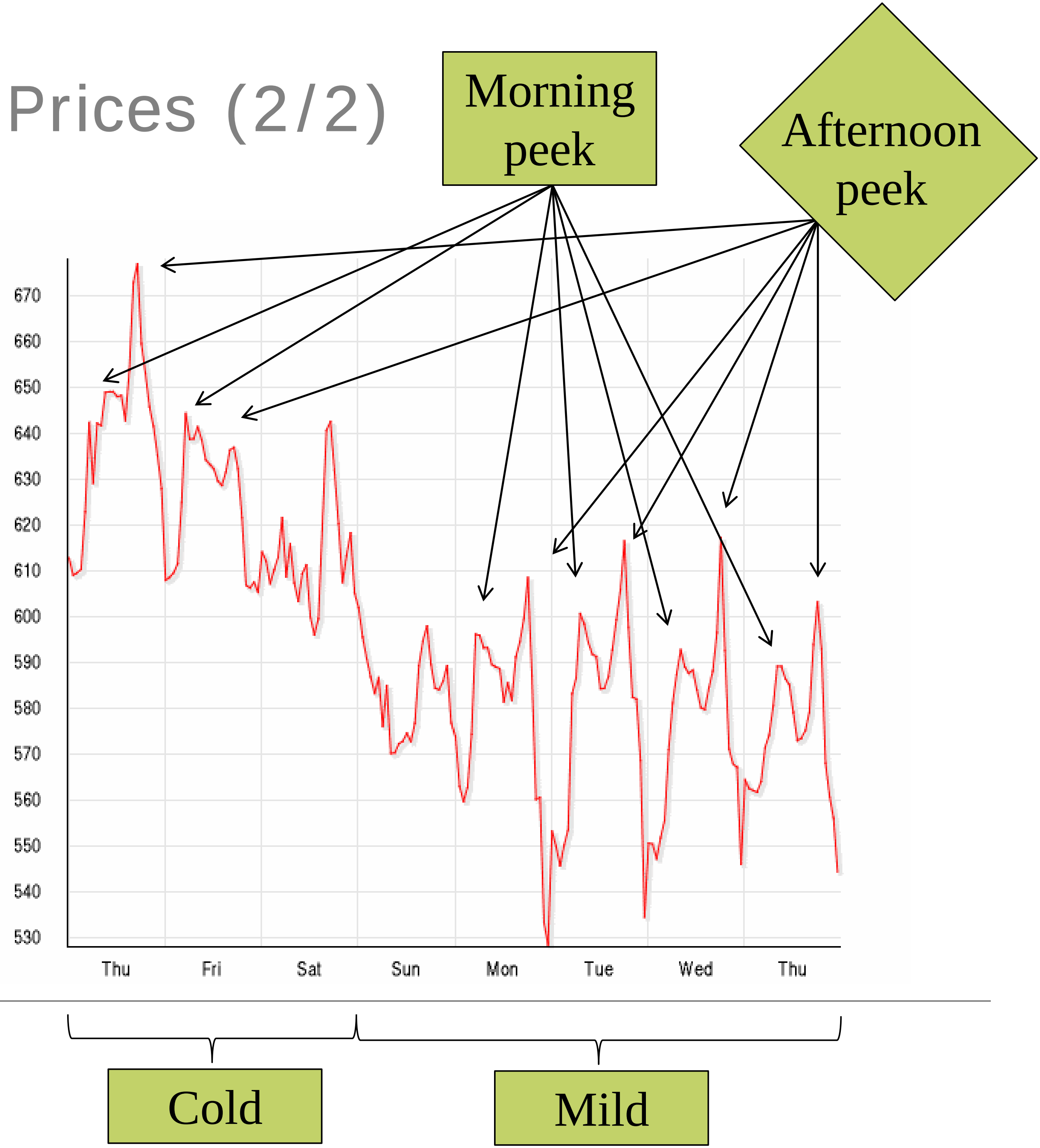
Nord Pool Prices (2/2)

Stockholm 13-20 January 2011

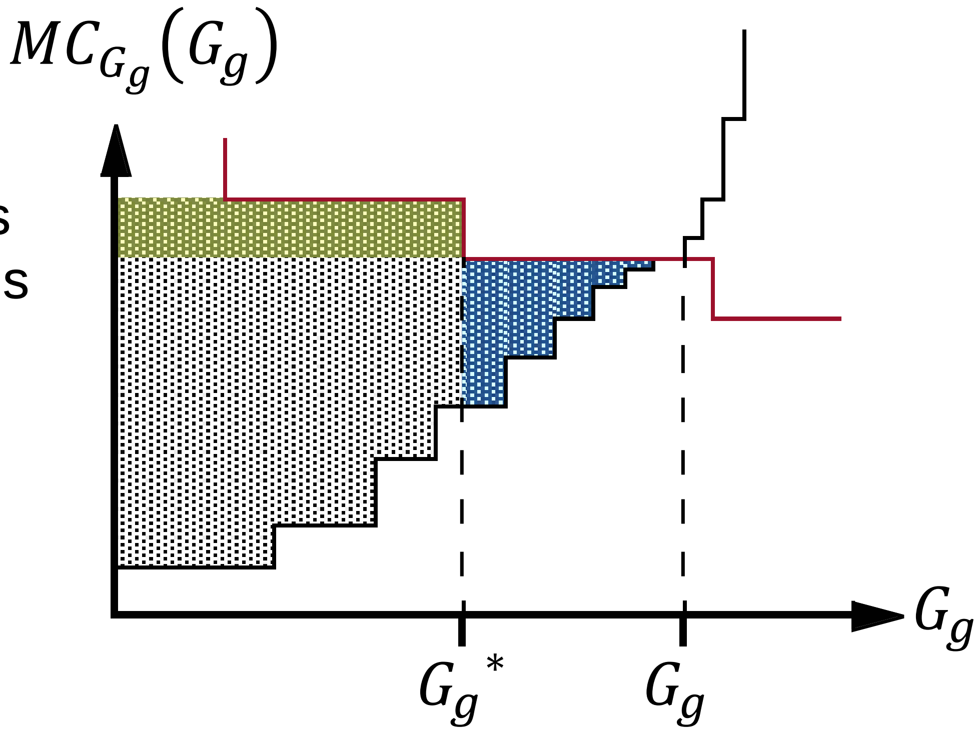


Market Power

- Market power arises
  - when a player has such a large market share
  - that the actions of that individual player
  - will affect the market price,
  - i.e. the player is a price setter.
- A price setter can increase its own profits
  - compared to the ideal market …
  - … this will decrease the total surplus.
- It is illegal to exercise market power
  - (but it is hard to prove that a player actually is using market power).

Price-setting producer

- In the ideal market,
  - the producer would choose the production level G_g,
  - where the marginal costs of the company intersects the demand curve.
- However, reducing the production to $G_g{}^* < G_g$ is profitable if
  - the lost earnings (blue area) is smaller than the increased earnings (green area).



Example 3.5 – Problem (1/3)

- Large producer, AB Kraftjätten
  - 60 TWh/year, 40 SEK/MWh
- Remaining producers
  - small capacity compared to market turnover
  - Marginal costs vary linearly between 40 SEK/MWh and 200 SEK/MWh
- Demand, 80 TWh, not price sensitive
- Assume
  - Perfect information
  - *continues ...*

Example 3.5 – Problem (2/3)

- Assume
  - *continued …*
  - That there are neither any
    - Capacity
    - Transmission, nor
    - Reservoir limitations
- What would the price be
  - If we had perfect competition?
  - If AB Kraftjätten maximizes its profits by utilizing its power as a price setter?

Example 3.5 – Problem (3/3)

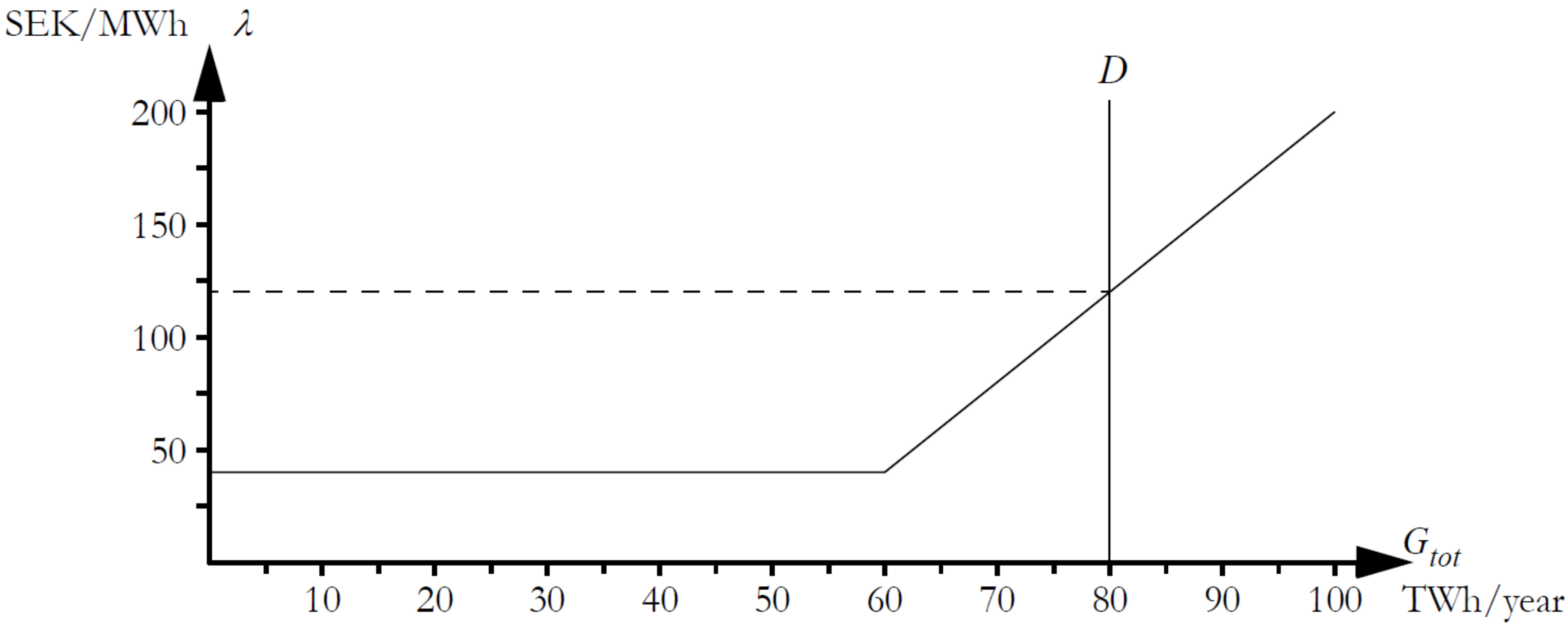


Figure 3.10 Supply and demand of the electricity market in example 3.5.

Example 3.5 – Solution (1/5)

- Perfect competition
  - $60 + \left(\frac{\lambda - 40}{200 - 40}\right) \cdot 40 = 80 \Rightarrow \lambda = 120$
- AB Kraftjätten maximizes profit
  - Let G denote the annual generation of the company
  - $\lambda(G) = 120 - 4(G - 60) = 360 - 4 \cdot G$, where
  - The slope, 4, comes from $\frac{200-40}{40} = \frac{160}{40} = 4$, and where
  - $G \leq 60$, related to the company's capacity, and where
  - $G + 40 \geq 80 \Rightarrow 40 \leq G$,
  - where 40 represents the competitors' total capacity,
  - and where 80 represents the total demand
  - *continues ...*

Example 3.5 – Solution (2/5)

- AB Kraftjätten maximizes
  - *continued …*
  - Surplus of company: $PS(G) = G \cdot \lambda\,(G) - 40 \cdot G = 360 \cdot G - 4G^2 - 40 \cdot G = 320 \cdot G - 4G^2$
  - Maximum is either at
    - Endpoint(s), or
    - Stationary point(s)
  - However, we solve it graphically today!

Example 3.5 – Solution (3/5)

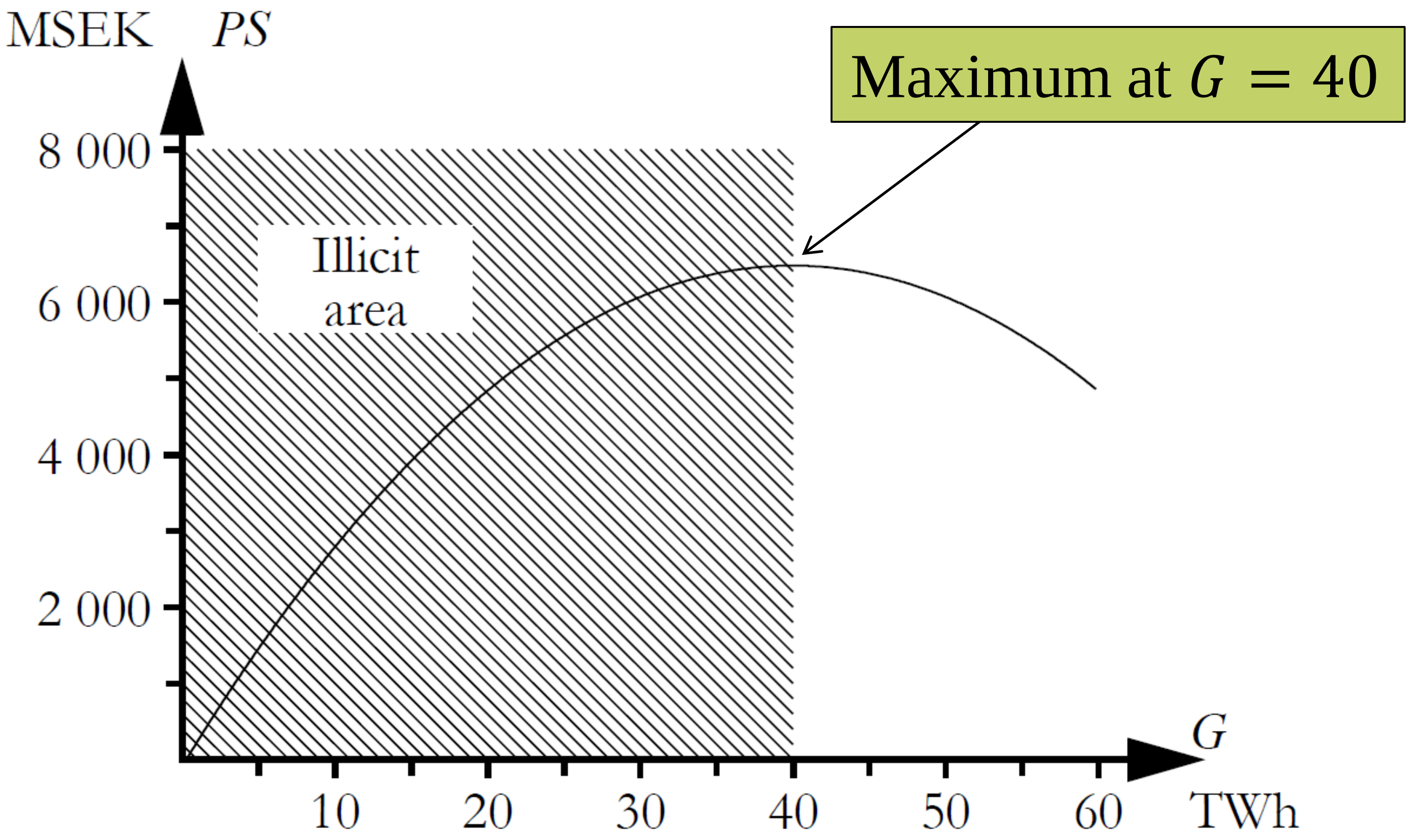


Figure 3.11 The surplus of AB Kraftjätten as a function of chosen annual generation.

Example 3.5 – Solution (4/5)

- AB Kraftjätten maximizes
  - *continued ...*
  - Surplus of company: $PS(G) = G \cdot \lambda(G) - 40 \cdot G = 360 \cdot G - 4G^2 - 40 \cdot G = 320 \cdot G - 4G^2$
  - Maximum is either at
    - Endpoint(s), or
    - Stationary point(s)
  - $\lambda(40) = 120 - 4(40 - 60) = 120 + 80 = 200$

Example 3.5 – Problem (5/5)

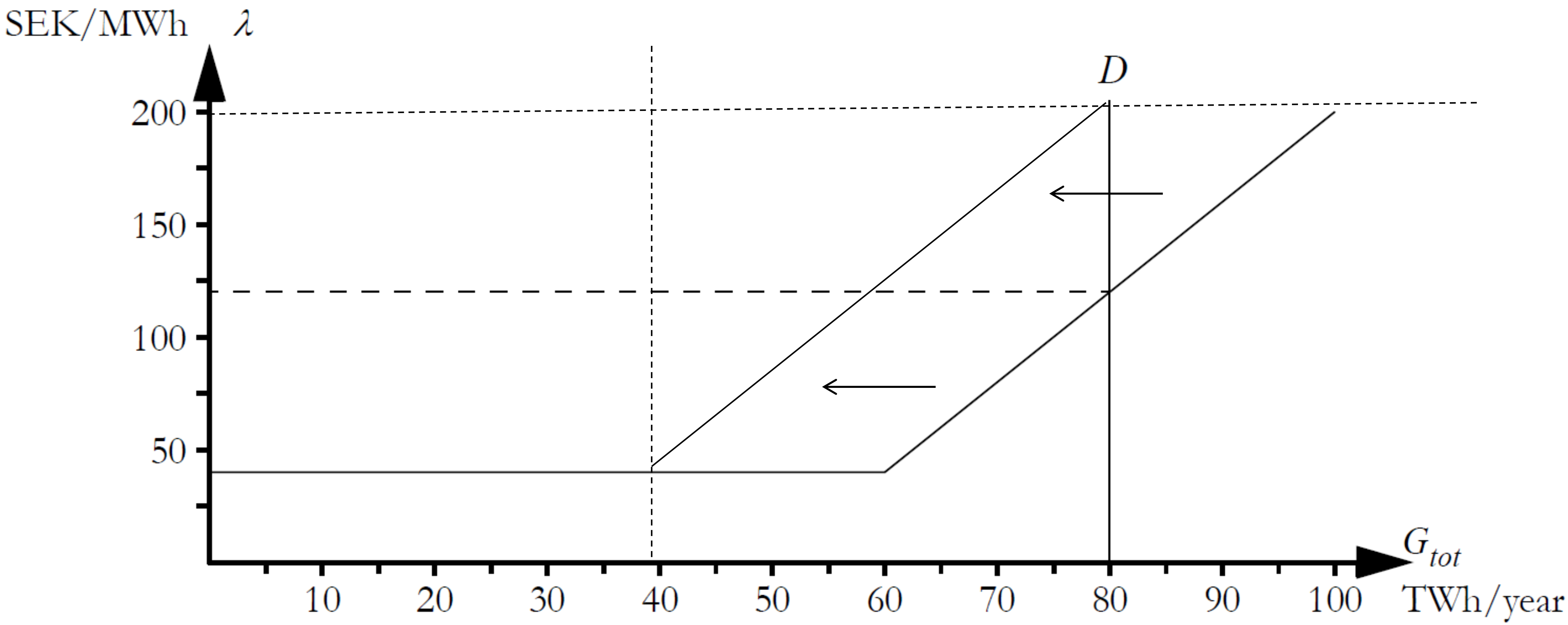


Figure 3.10 Supply and demand of the electricity market in example 3.5.

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Time for ”Lecture Assignments”

- On another slideshow...