Do costs fall faster than revenues? Renewable Electricity Subsidies' Dynamics

Richard Green and Thomas-Olivier Léautier

Imperial College London BUSINESS SCHOOL

A Subsidy Race

Toulouse School of Economics

- Subsidies to renewable generation can be justified by learning-by-doing externalities
  - Costs will fall over time
- The value of the output from renewable generators depends on the mix of plant on the system
  - Too much of a good thing falls in value
- Which of these effects will dominate in practice?

Imperial College London BUSINESS SCHOOL

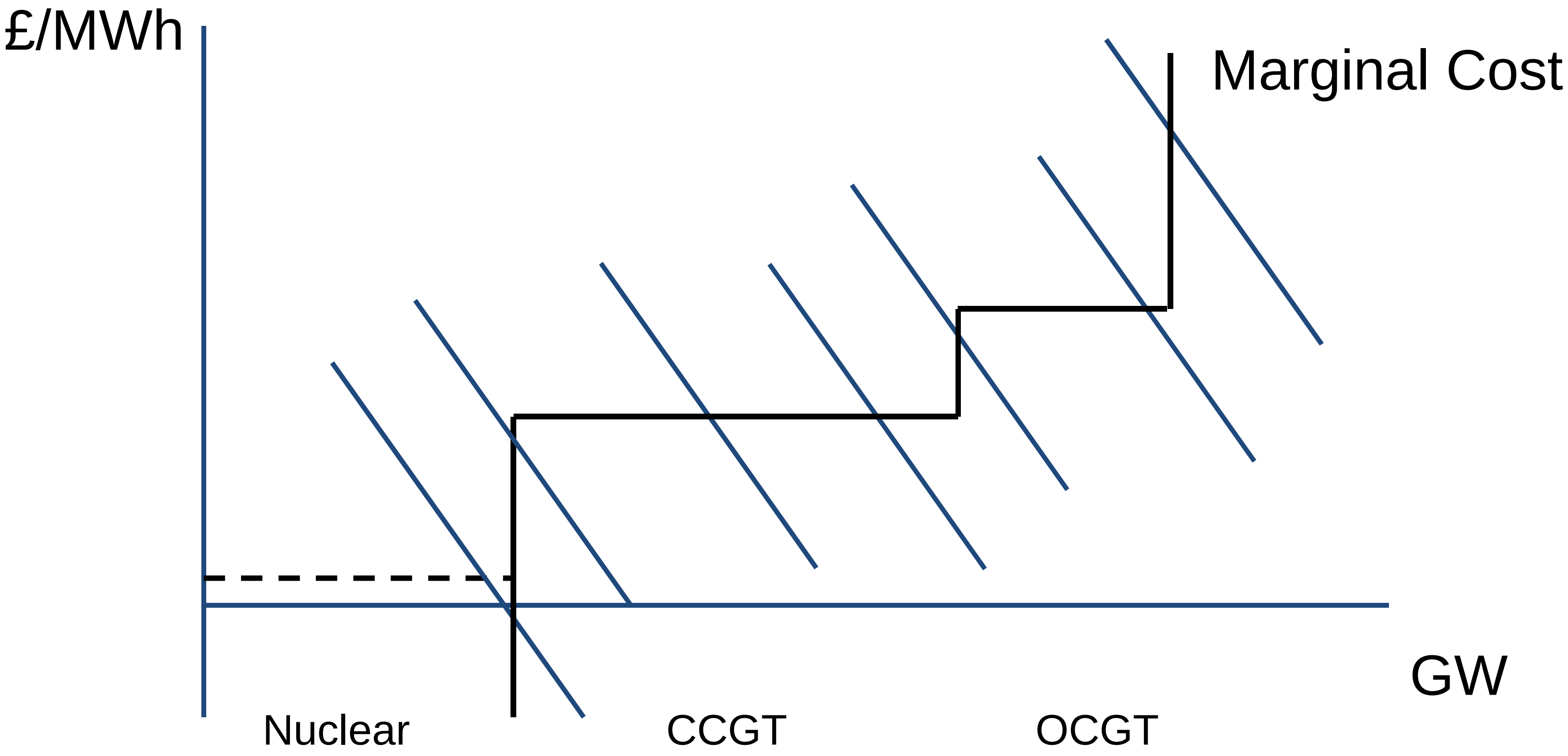
What we will present

Toulouse School of Economics

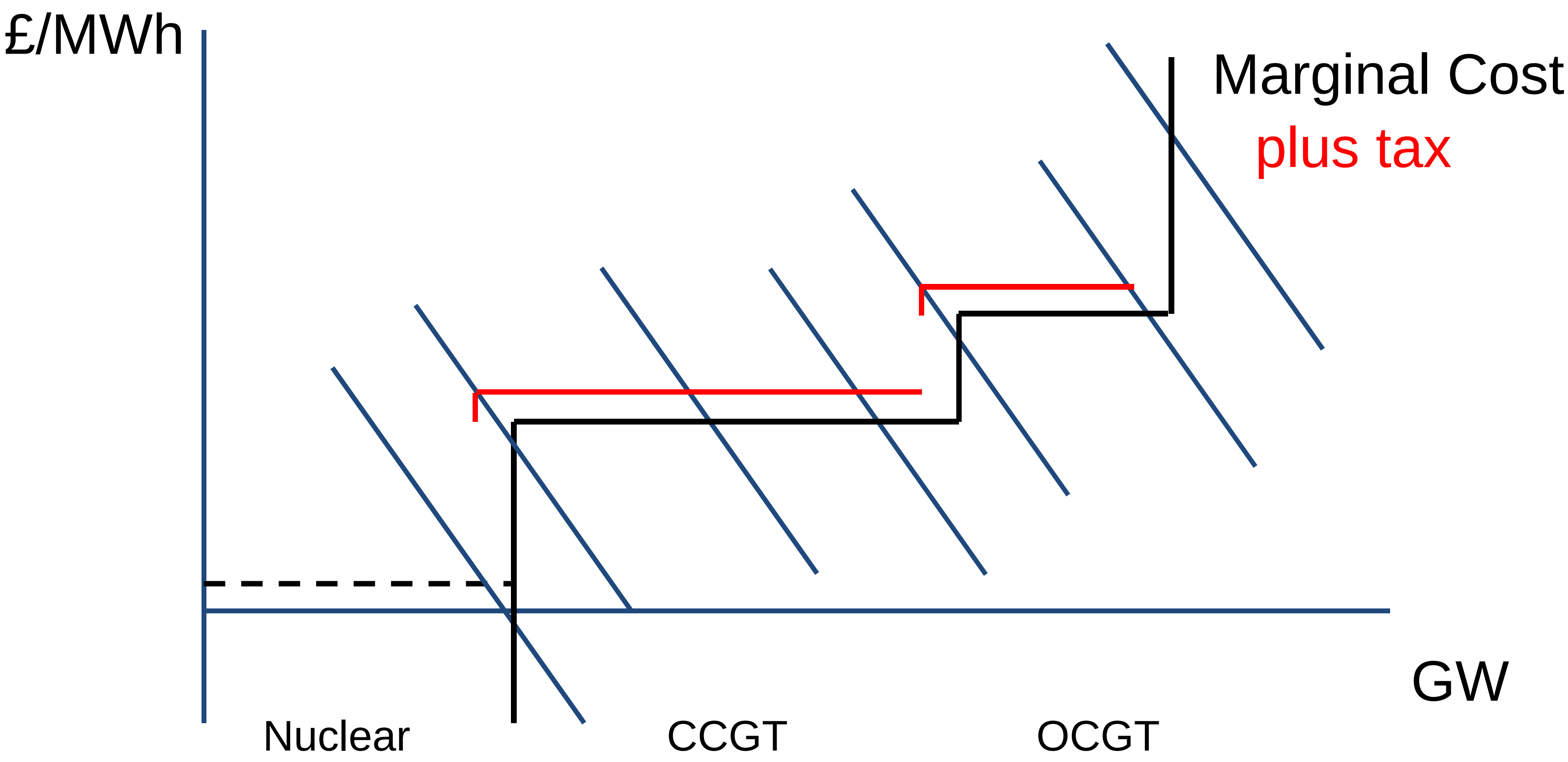
- We present:
  1. the basic story
  2. a theoretical model
  3. a numerical simulation

- We find:
  1. For numbers fitted to wind energy in Great Britain, the falling price effect appears to dominate so subsidies are “always” required (for our fuel and carbon prices)
  2. Low learning rates lead to large welfare losses
     - Marginal loss is £100 per kW per year at 30 GW
     - Cumulative loss of £2 billion per year

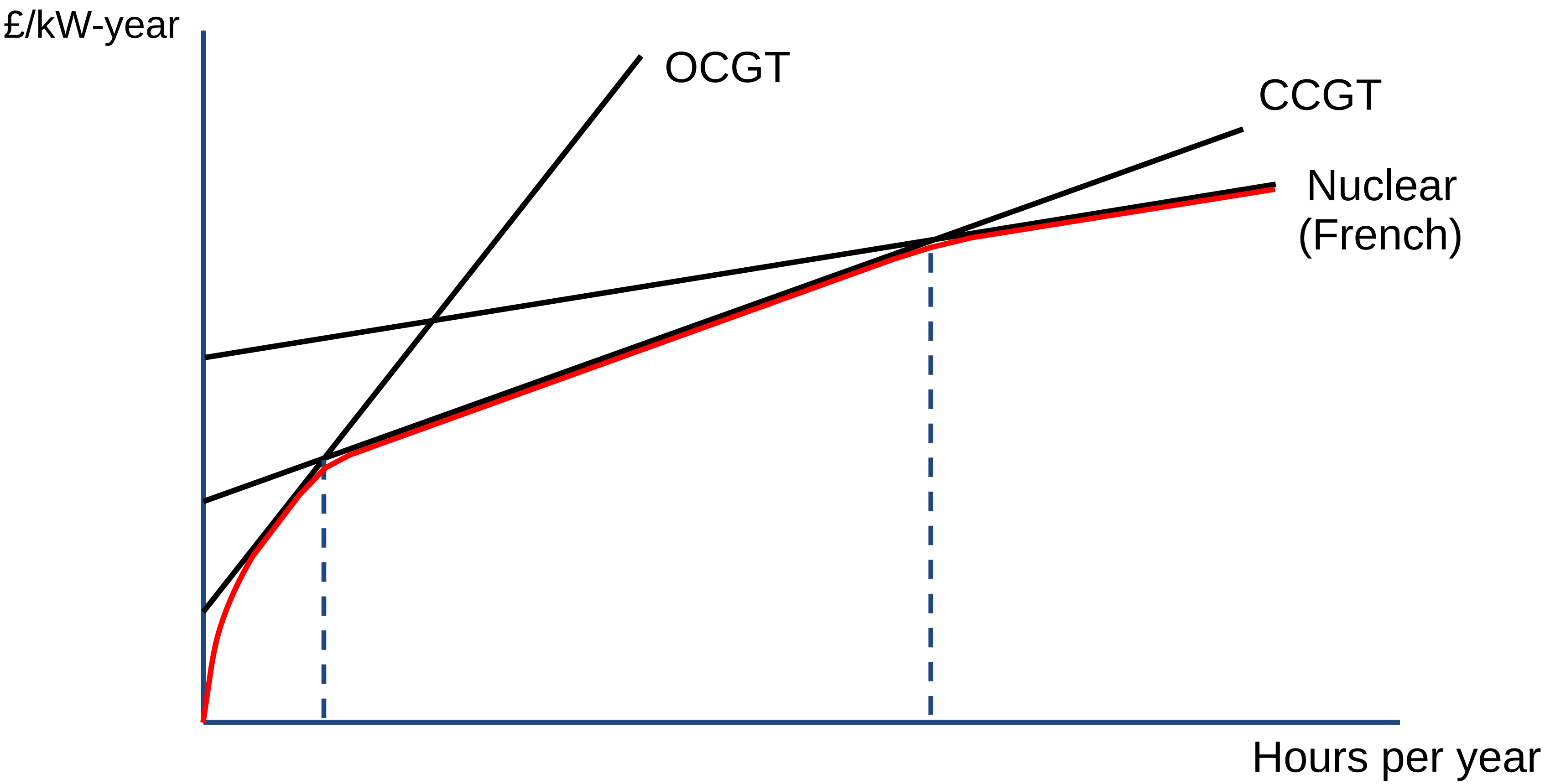
Demand and Supply



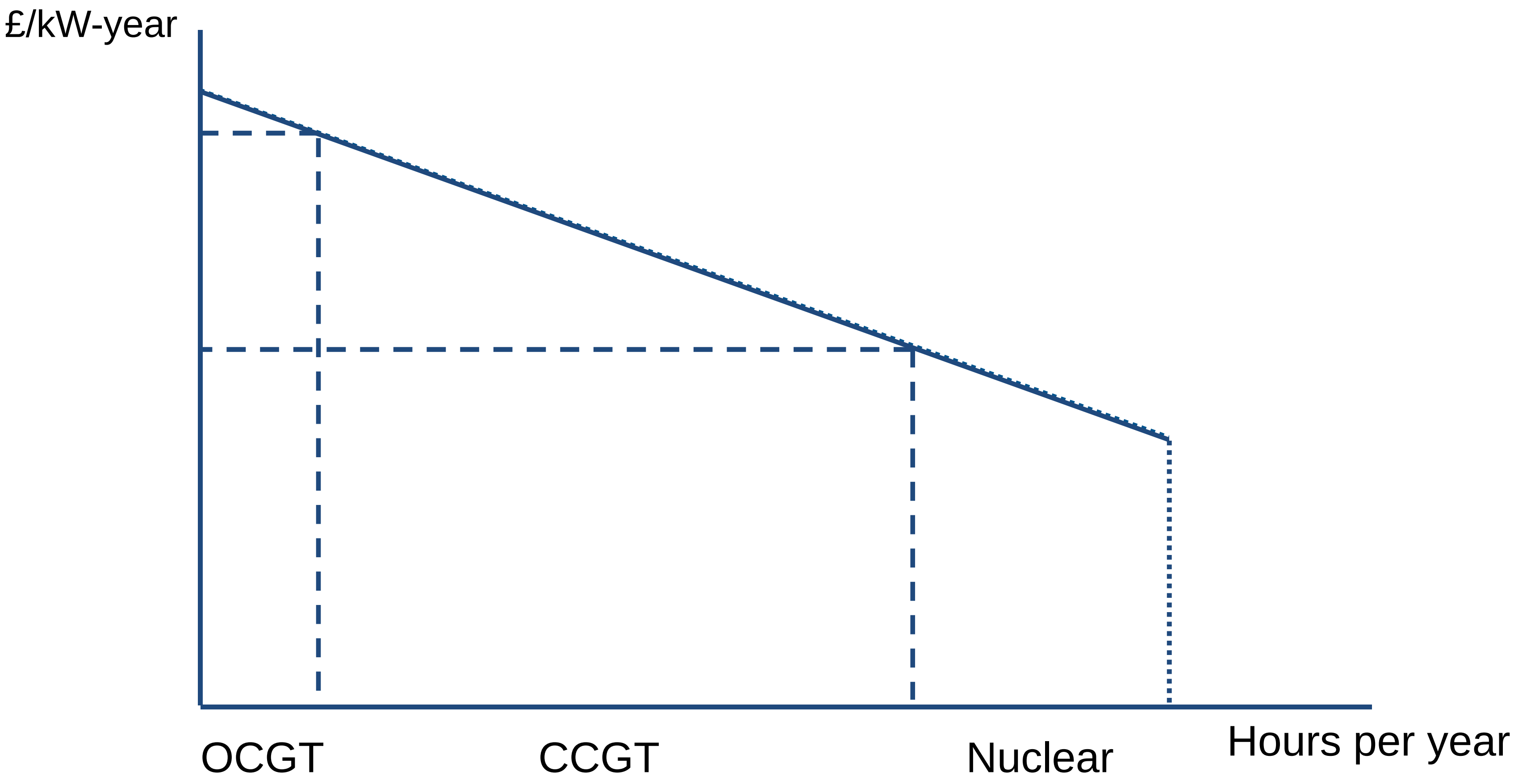
Demand and Supply



Costs & Revenues



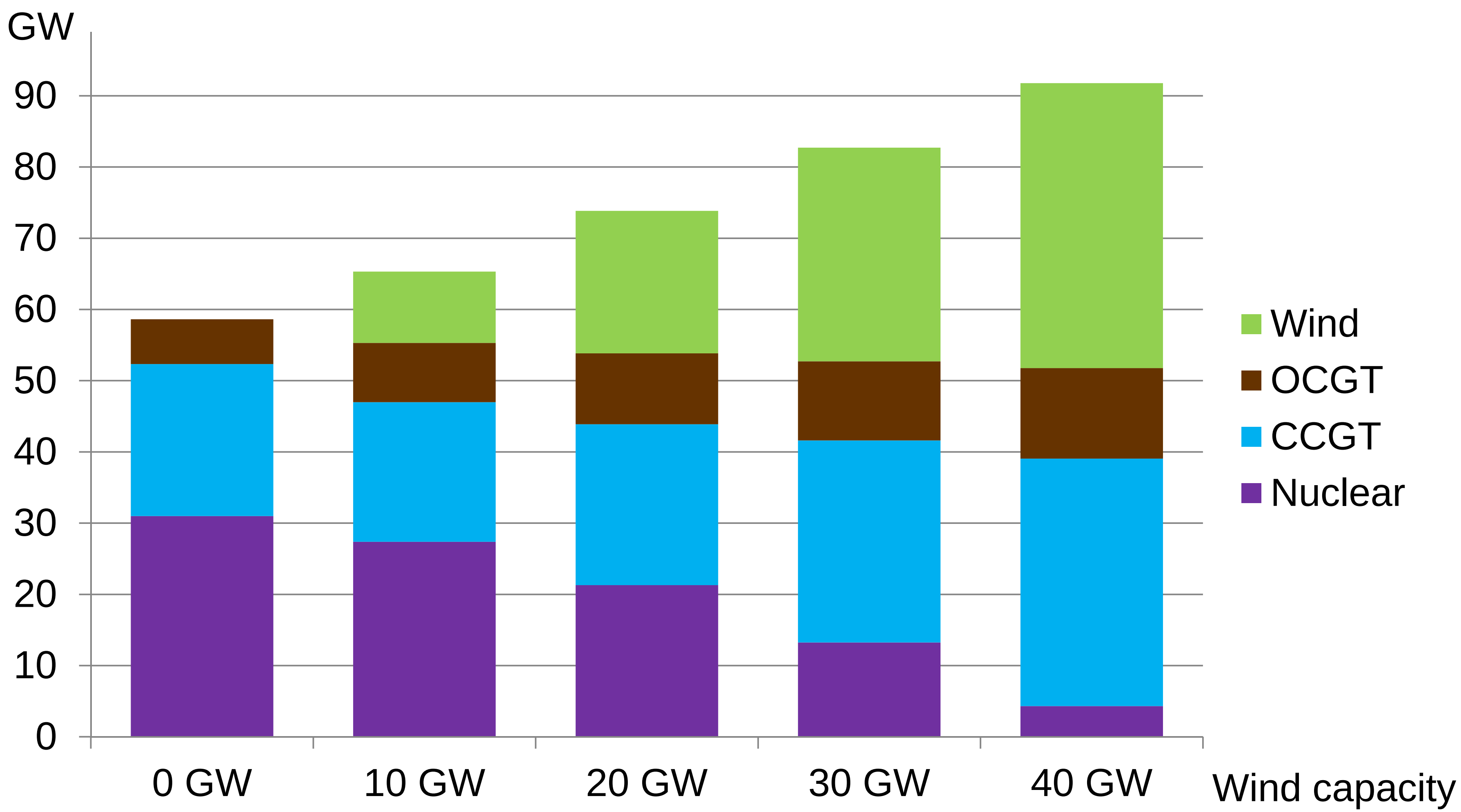
Capacity and Load



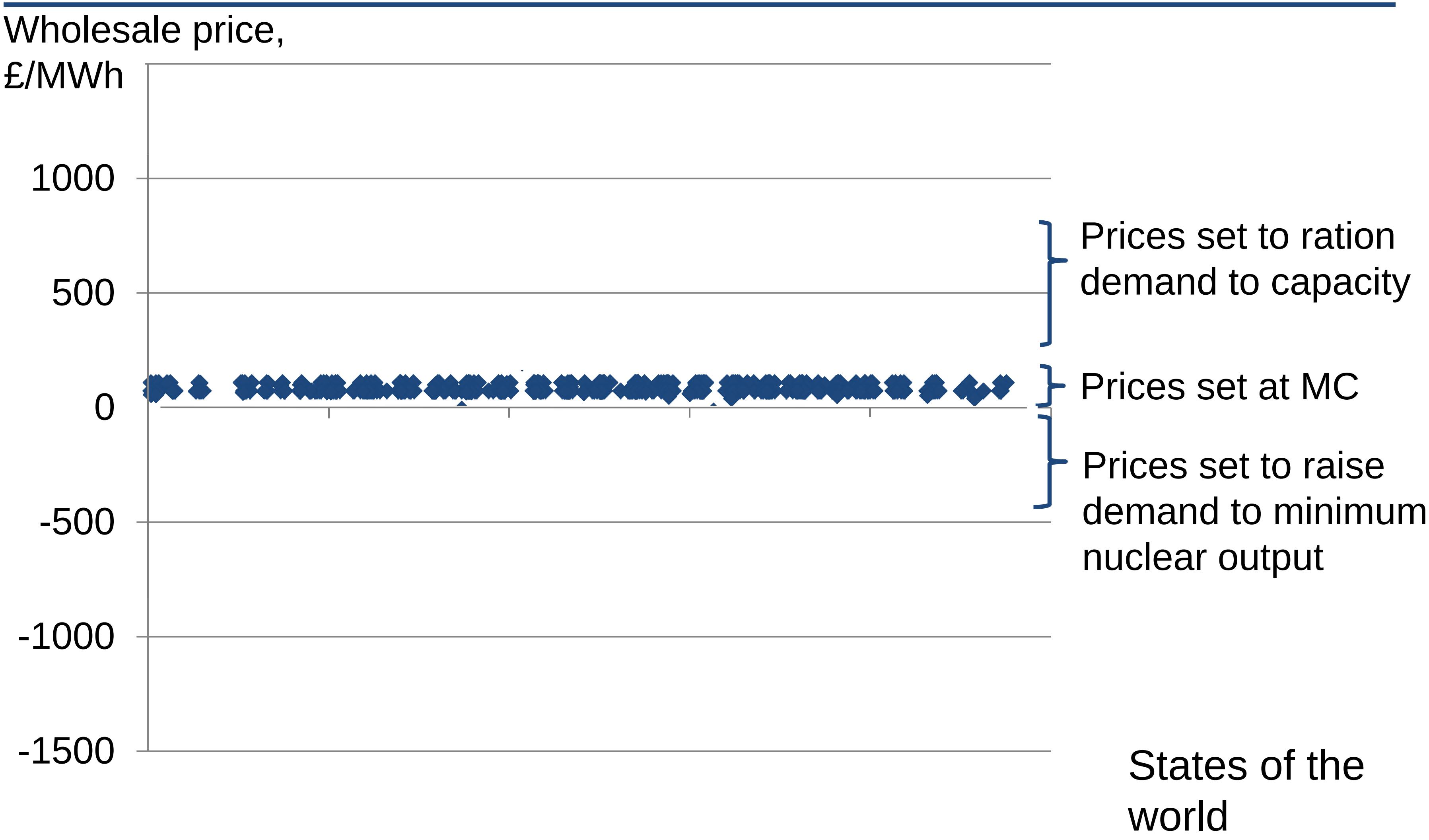
Imperial College London BUSINESS SCHOOL

Capacity Mix

Toulouse School of Economics

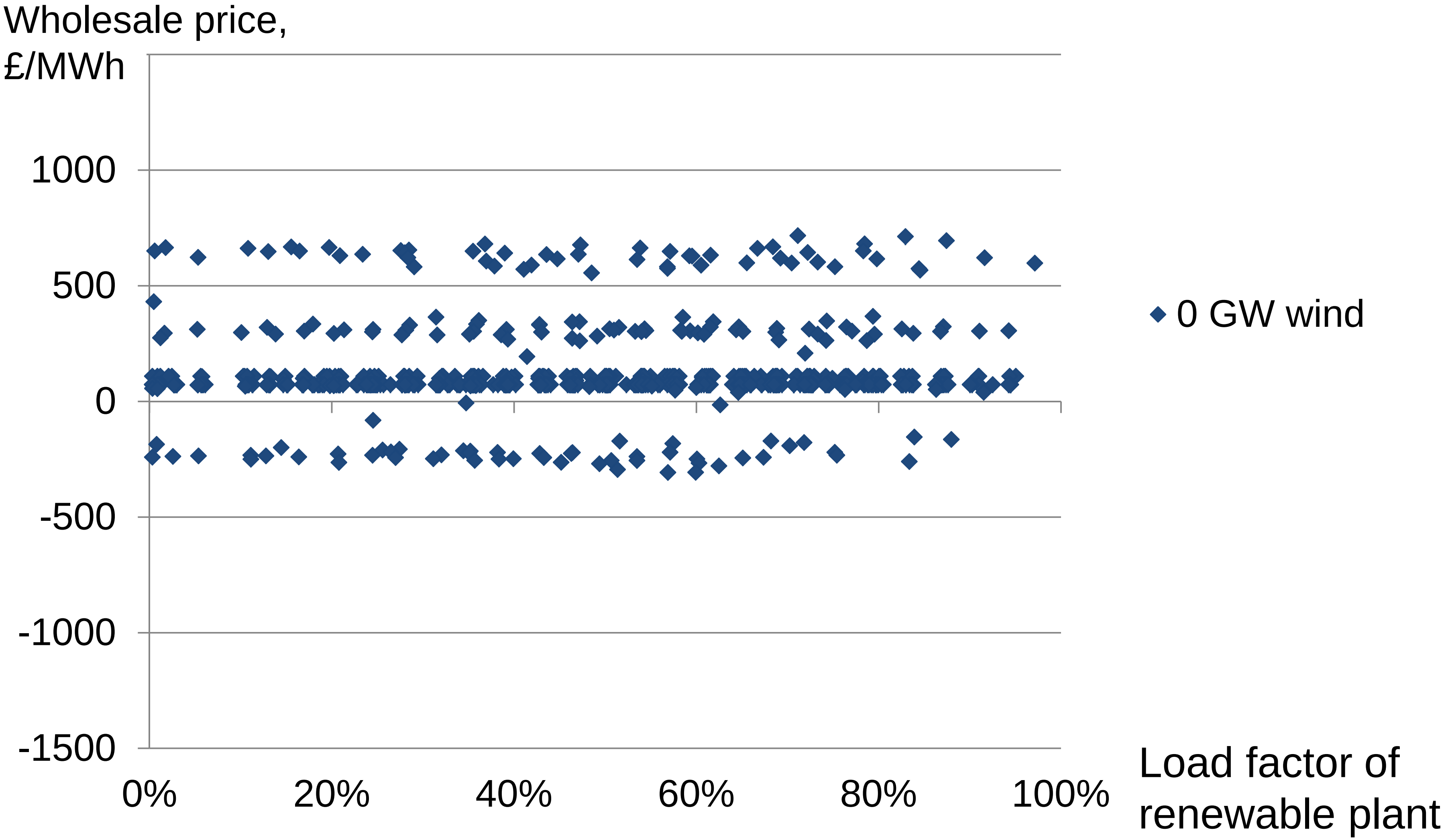


Prices

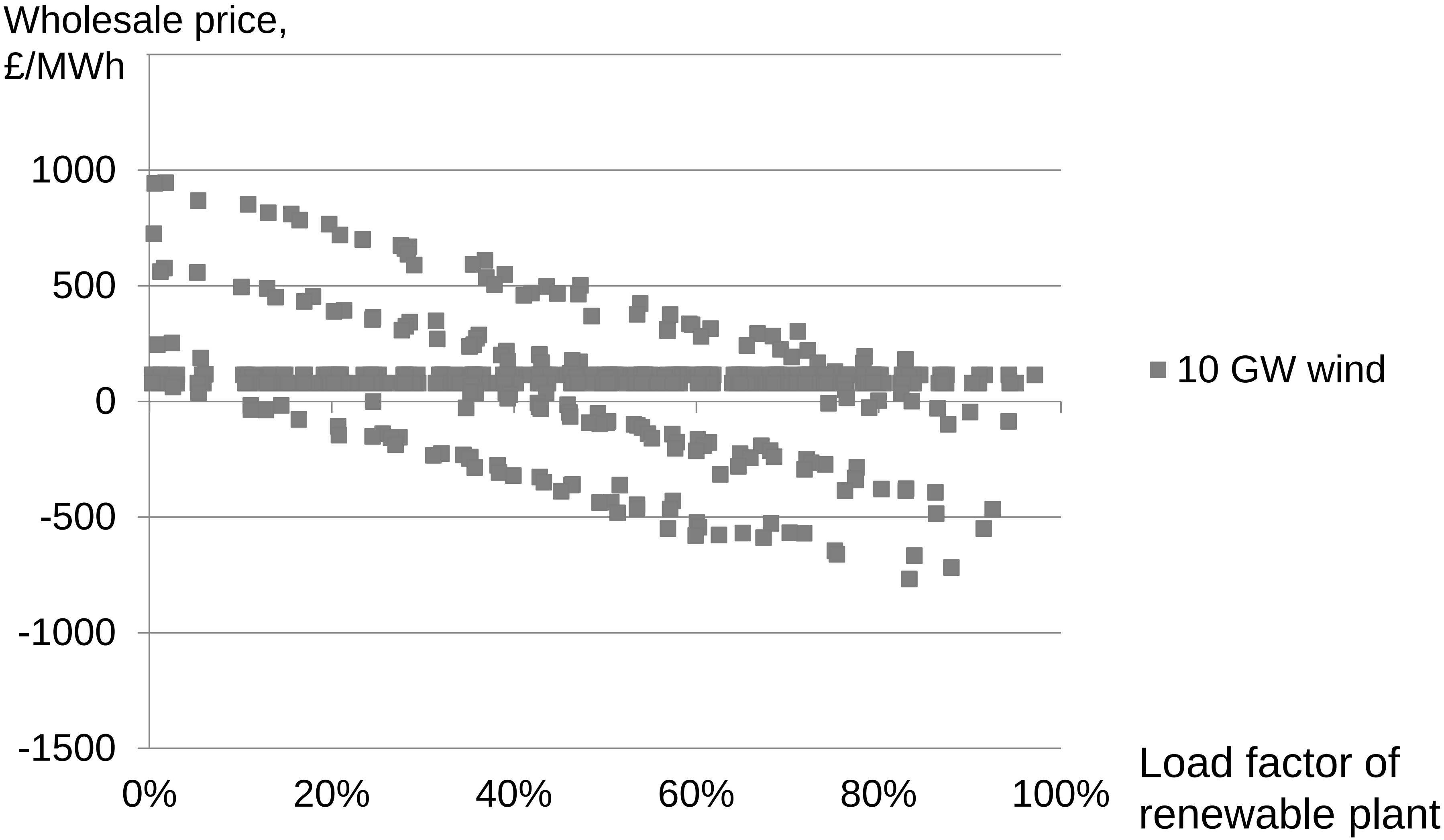


Wholesale price, £/MWh
1000
500
0
-500
-1000
-1500
Prices set to ration demand to capacity
Prices set at MC
Prices set to raise demand to minimum nuclear output
States of the world

Load Factors & Prices



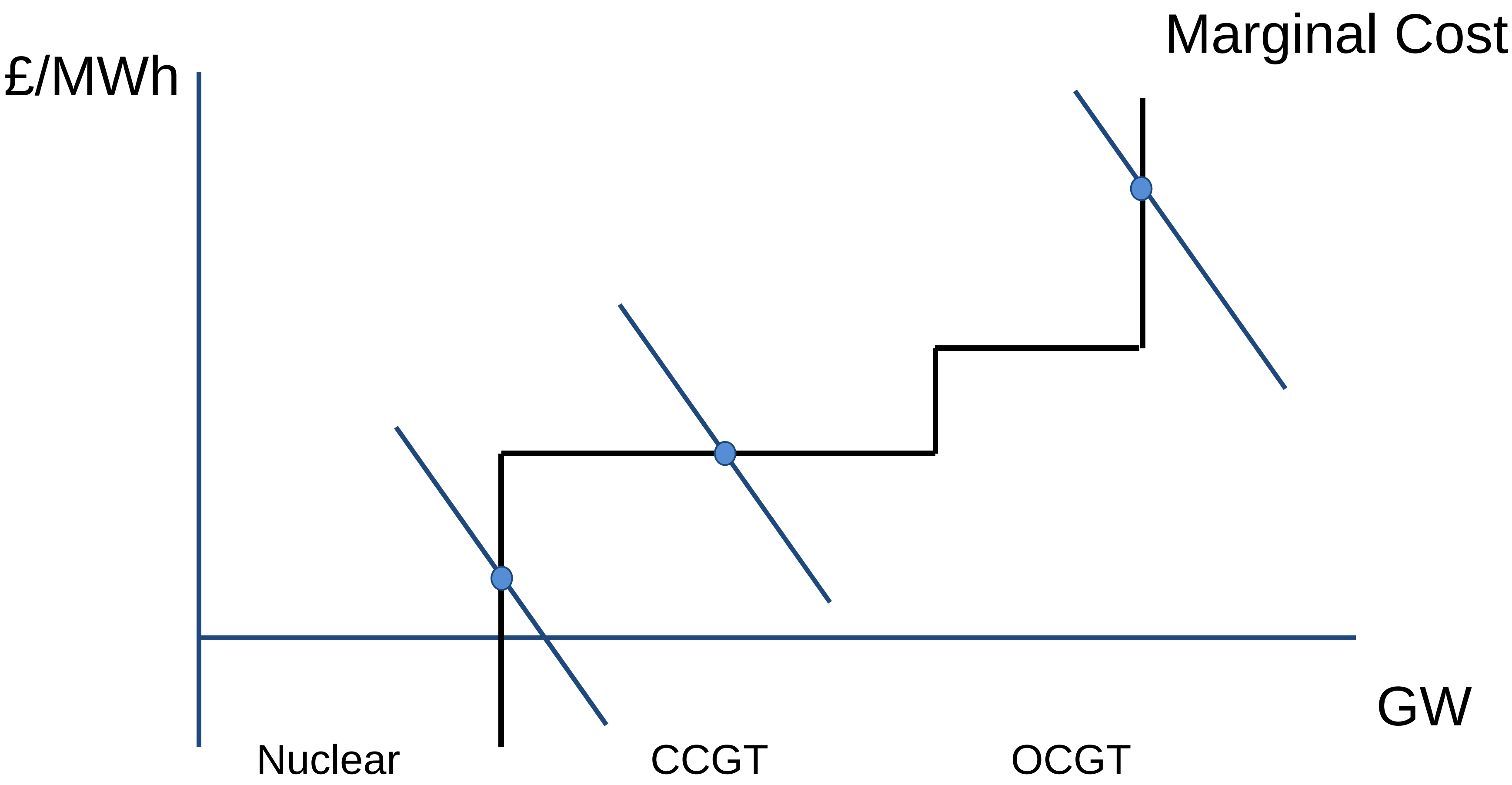
Load Factors & Prices



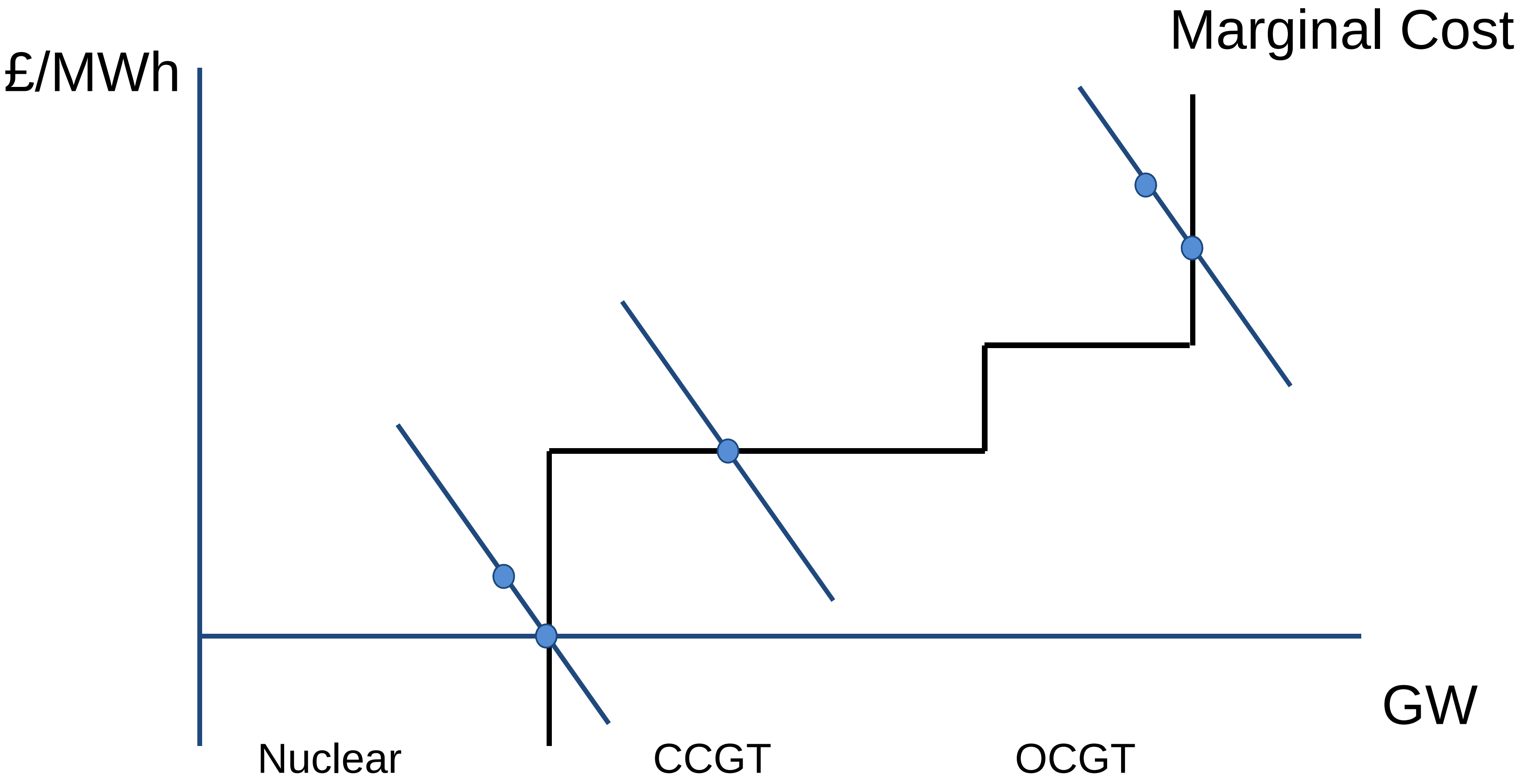
Imperial College London BUSINESS SCHOOL

Demand and Supply

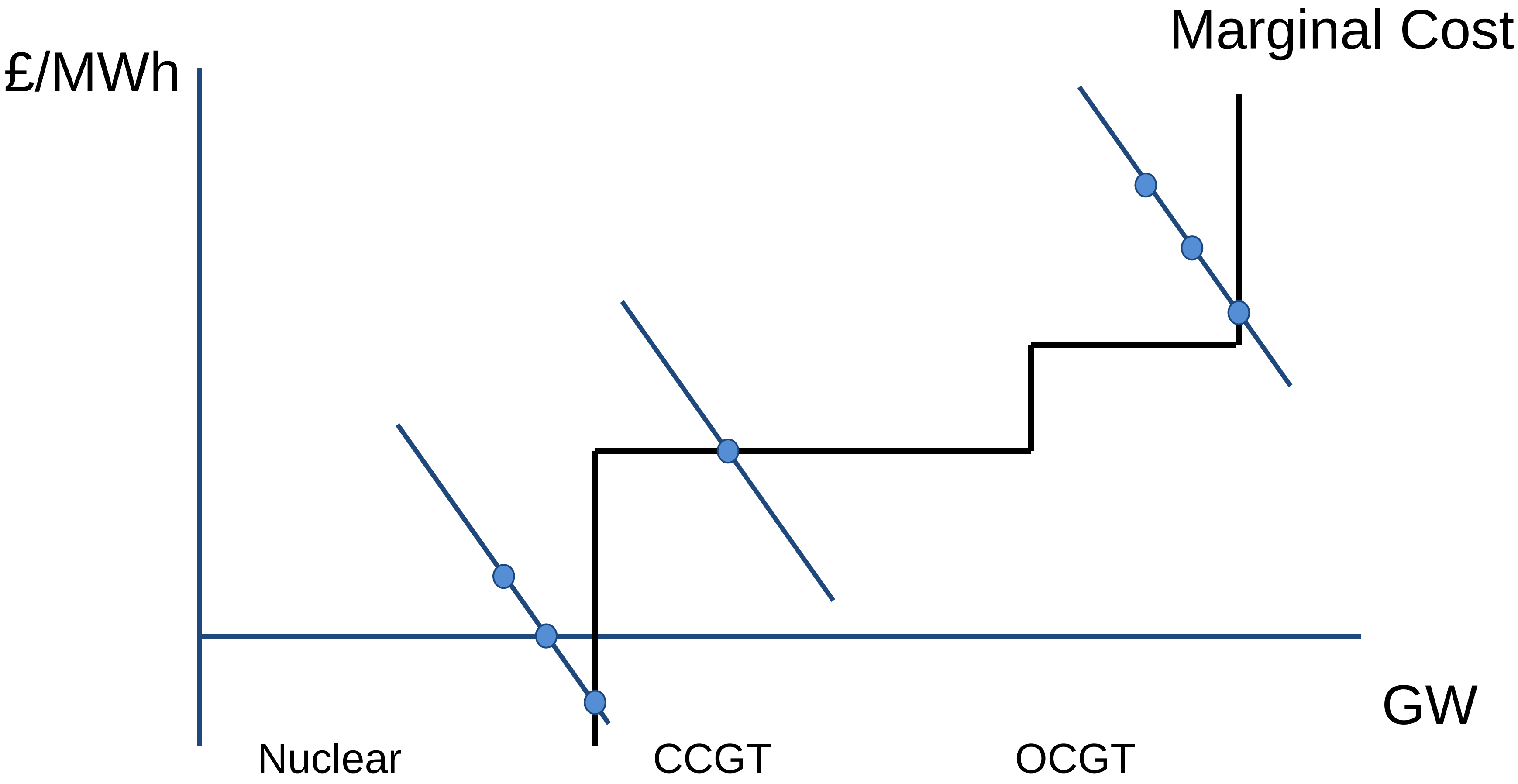
Toulouse School of Economics



Demand and Supply



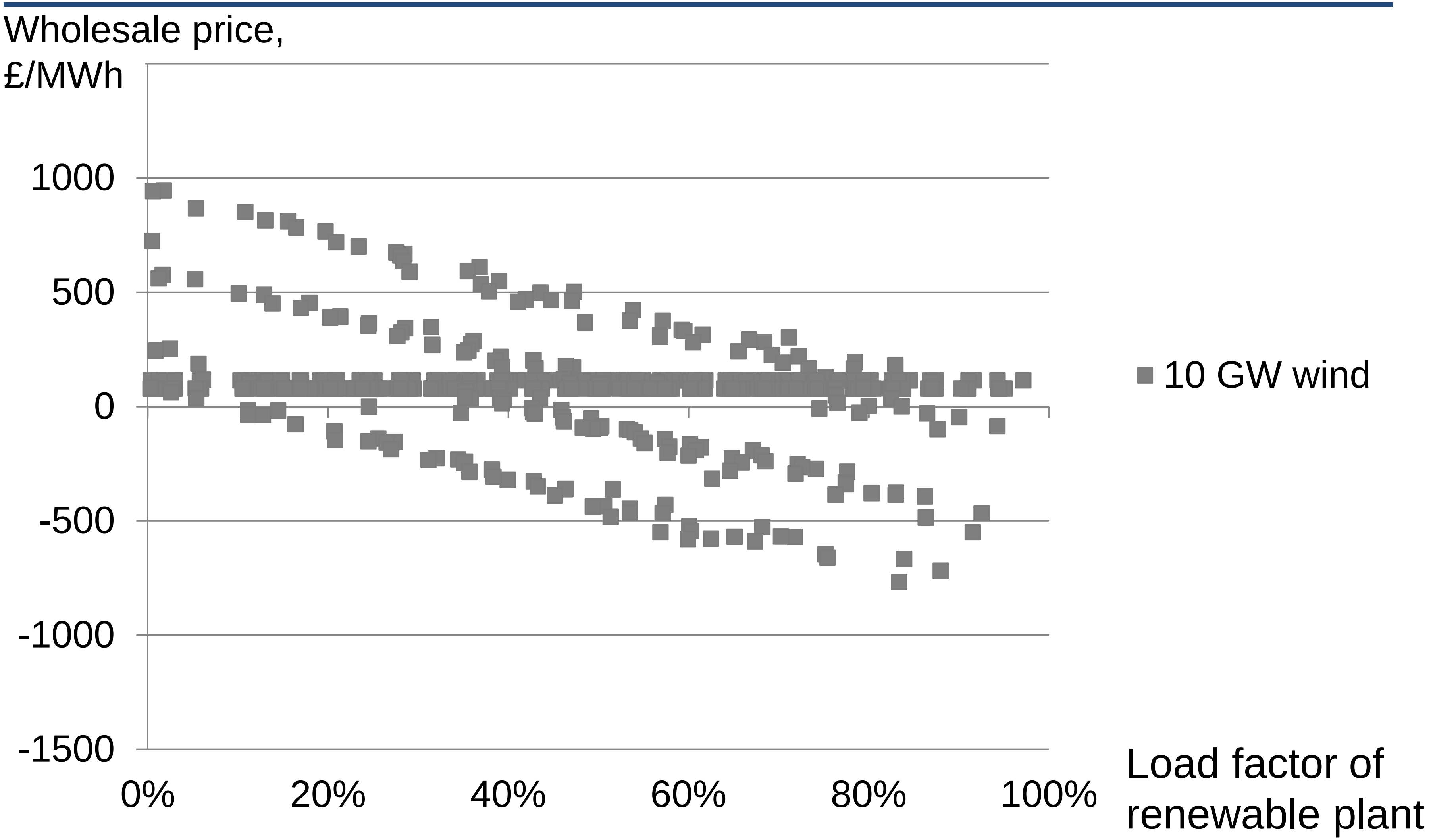
Demand and Supply



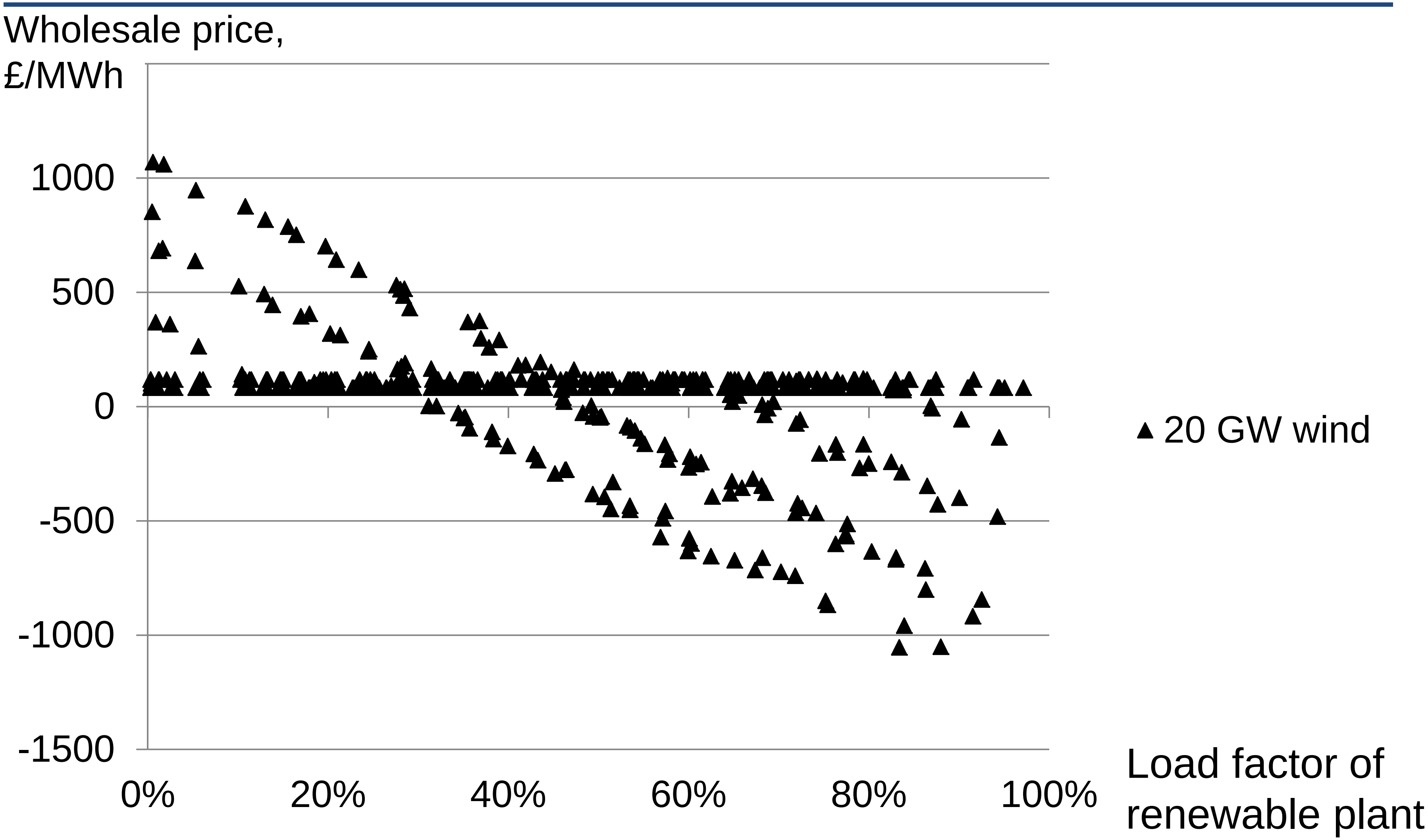
Imperial College London BUSINESS SCHOOL

Load Factors & Prices

Toulouse School of Economics



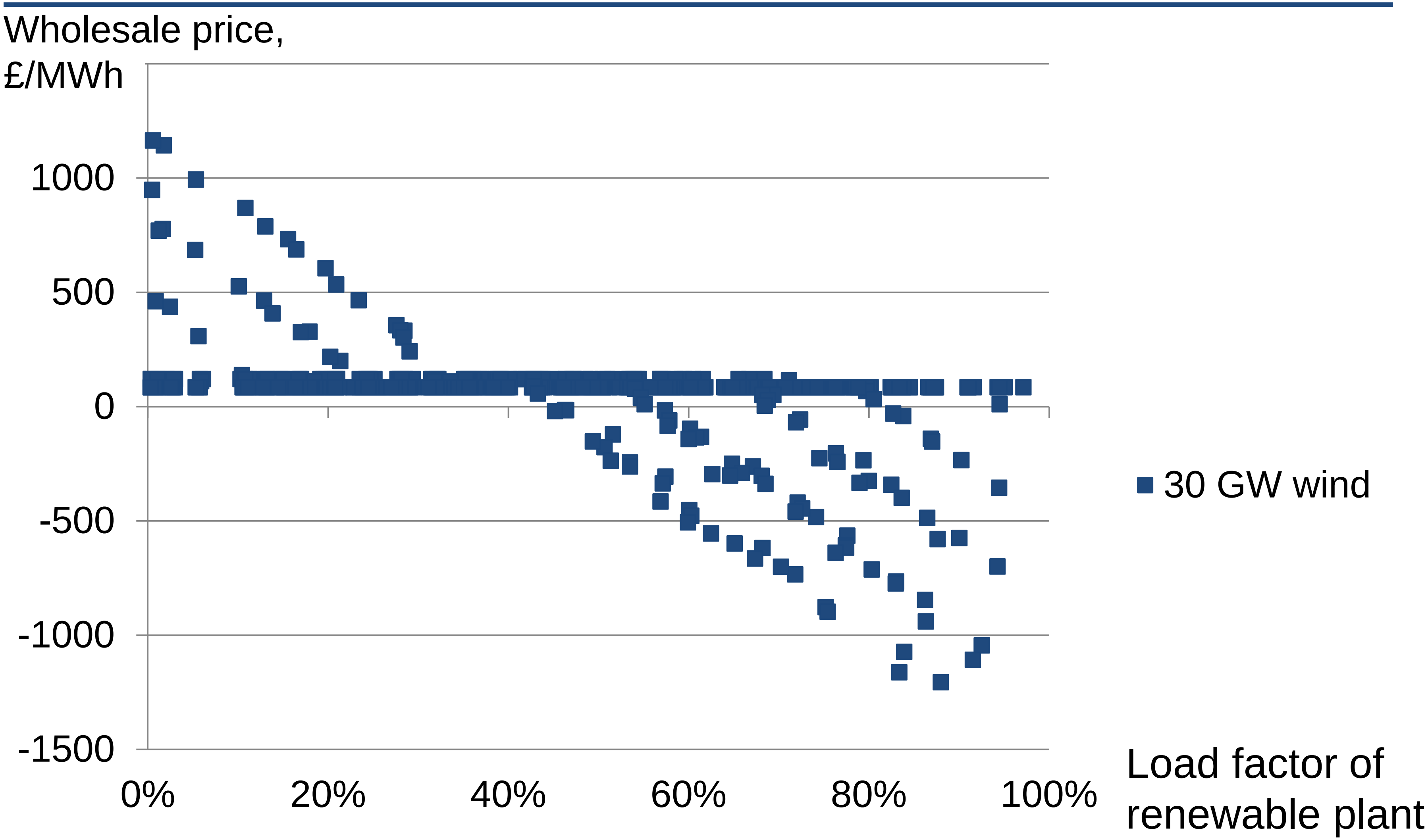
Load Factors & Prices



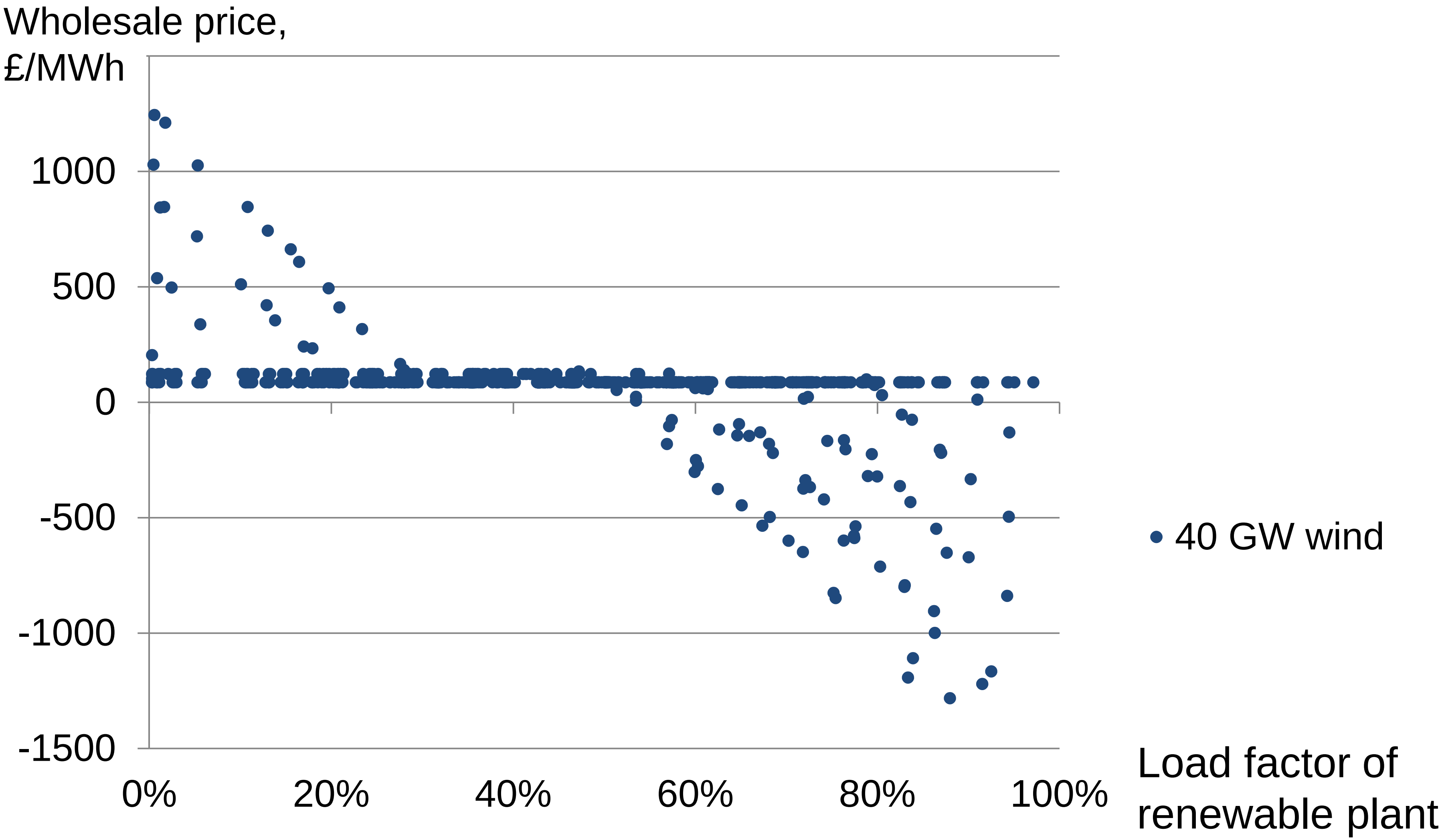
Imperial College London BUSINESS SCHOOL

Load Factors & Prices

Toulouse School of Economics



Load Factors & Prices



Imperial College London BUSINESS SCHOOL

The model

Toulouse School of Economics

- Renewable capacity marginal cost $r_0(K_0)$ falls with learning by doing, cumulative cost $R_0(K_0)$
- Renewables are paid a feed-in tariff to cover their cost

$$f(K_0)\,\mathbb{E}[\alpha(\theta)] = r_0(K_0)$$

where α is renewable availability in state θ

- First units require a subsidy $\varphi(K_0)$ (in € per MW of capacity per hour) as their cost exceeds expected revenue at market prices

$$\varphi(K_0) = \max\left(r_0(K_0) - \mathbb{E}[\alpha(\theta)\,p(\theta, K_0)], 0\right)$$

- Subsidy is financed via a tax, τ, paid by consumers

Imperial College London BUSINESS SCHOOL

Marginal impact of renewable capacity K_0

Toulouse School of Economics

- No change in (time-weighted) average price, $p(\theta,K_0)$

$$\mathbb{E}\left[\frac{\partial p}{\partial K_0}(\theta, K_0)\right] = 0$$

- Reduction in conventional installed capacity

$$\frac{dK_n}{dK_0} = -\frac{1}{b}\frac{d\tau}{dK_0} - \mathbb{E}\left[\alpha(\theta)\,|v_n\right]$$

  - K_n is cumulative capacity of first n types (ordered by MC)
  - b is demand curve slope

Imperial College London
BUSINESS SCHOOL

Marginal tax impact

Toulouse School of Economics

- (Expected) Tax revenues cover cumulative capital cost of renewable generation, $R_0(K_0)$

$$R_0(K_0) = \tau \bar{D}(K_0) + \mathbb{E}\left[p(\theta, K_0)\,\alpha(\theta)\,K_0\right]$$

where expected demand is

$$\bar{D}(K_0) = \mathbb{E}\left[D\left(p(K_0, \theta) + \tau(K_0), \theta\right)\right]$$

- Full differentiation leads to

$$\frac{d\tau}{dK_0}\bar{D}(K_0) = \varphi(K_0) - \tau\frac{d\bar{D}}{dK_0} - \mathbb{E}\left[a(\theta)\,\frac{\partial p}{\partial K_0}\right]K_0$$

the €/MW per hour subsidy for incremental capacity K_0

change in market revenues

Exploiting the structure of the supply curve (linear demand)

- Marginal demand reduction

$$\frac{d\bar{D}}{dK_0} = -\frac{1}{b}\frac{d\tau}{dK_0}$$

- Marginal revenues reduction for renewables

$$\mathbb{E}\left[\alpha\left(\theta\right)\frac{\partial p}{\partial K_0}\right] = -b\widehat{var}_{K_0}\left[\alpha\left(\theta\right)\right]$$

Conditional variance of α on the vertical parts of the supply curve

- Marginal tax increase

$$\frac{d\tau}{dK_0} = \frac{b\left(\varphi\left(K_0\right) + bK_0\widehat{var}_{K_0}\left[\alpha\left(\theta\right)\right]\right)}{b\bar{D}\left(0\right) - 2\tau\left(K_0\right)}$$

Marginal welfare change

- Marginal subsidy

$$\varphi(K_0) = r_0(K_0) - \mathbb{E}[p(\theta,0)\,\alpha(\theta)] + b\int_0^{K_0} \widehat{var}_x[\alpha(\theta)]\,dx$$

- Marginal welfare change

$$\frac{dH}{dK_0} = -\varphi(K_0) + \tau\frac{d\bar{D}}{dK_0}$$

$$\frac{dH}{dK_0} = -\left(\frac{\left(b\bar{D}(0) - \tau(K_0)\right)\varphi(K_0) + \tau(K_0)\,\widehat{var}_{K_0}[\alpha(\theta)]\,bK_0}{b\bar{D}(0) - 2\tau(K_0)}\right)$$

Constant conditional variance approximation

- Marginal subsidy

$$\varphi\left(K_0\right) = r_0\left(K_0\right) - \mathbb{E}\left[p\left(\theta, 0\right)\alpha\left(\theta\right)\right] + bK_0\widehat{var}\left[\alpha\left(\theta\right)\right]$$

- Marginal welfare change

$$\frac{dH}{dK_0} = -\left(\frac{\left(b\bar{D}\left(0\right) + \sqrt{\Delta\left(K_0\right)}\right)\varphi\left(K_0\right) + \left(b\bar{D}\left(0\right) - \sqrt{\Delta\left(K_0\right)}\right)\widehat{var}_{K_0}\left[\alpha\left(\theta\right)\right]bK_0}{2\sqrt{\Delta\left(K_0\right)}}\right)$$

Constant conditional variance approximation

- Marginal subsidy

$$\varphi(K_0) = r_0(K_0) - \mathbb{E}[p(\theta,0)\alpha(\theta)] + bK_0\widehat{var}[\alpha(\theta)]$$

- Marginal welfare change

$$\frac{dH}{dK_0} = -\left(\frac{\left(b\bar{D}(0)+\sqrt{\Delta(K_0)}\right)\varphi(K_0)+\left(b\bar{D}(0)-\sqrt{\Delta(K_0)}\right)\widehat{var}_{K_0}[\alpha(\theta)]\,bK_0}{2\sqrt{\Delta(K_0)}}\right)$$

where $\Delta(K_0) = \left(b\bar{D}(0)\right)^2 - 4b\Phi(K_0)$

and $\Phi(K_0) = R_0(K_0) + K_0\left(\widehat{var}[\alpha(\theta)]\,bK_0 - \mathbb{E}[p(\theta,0)\alpha(\theta)]\right).$

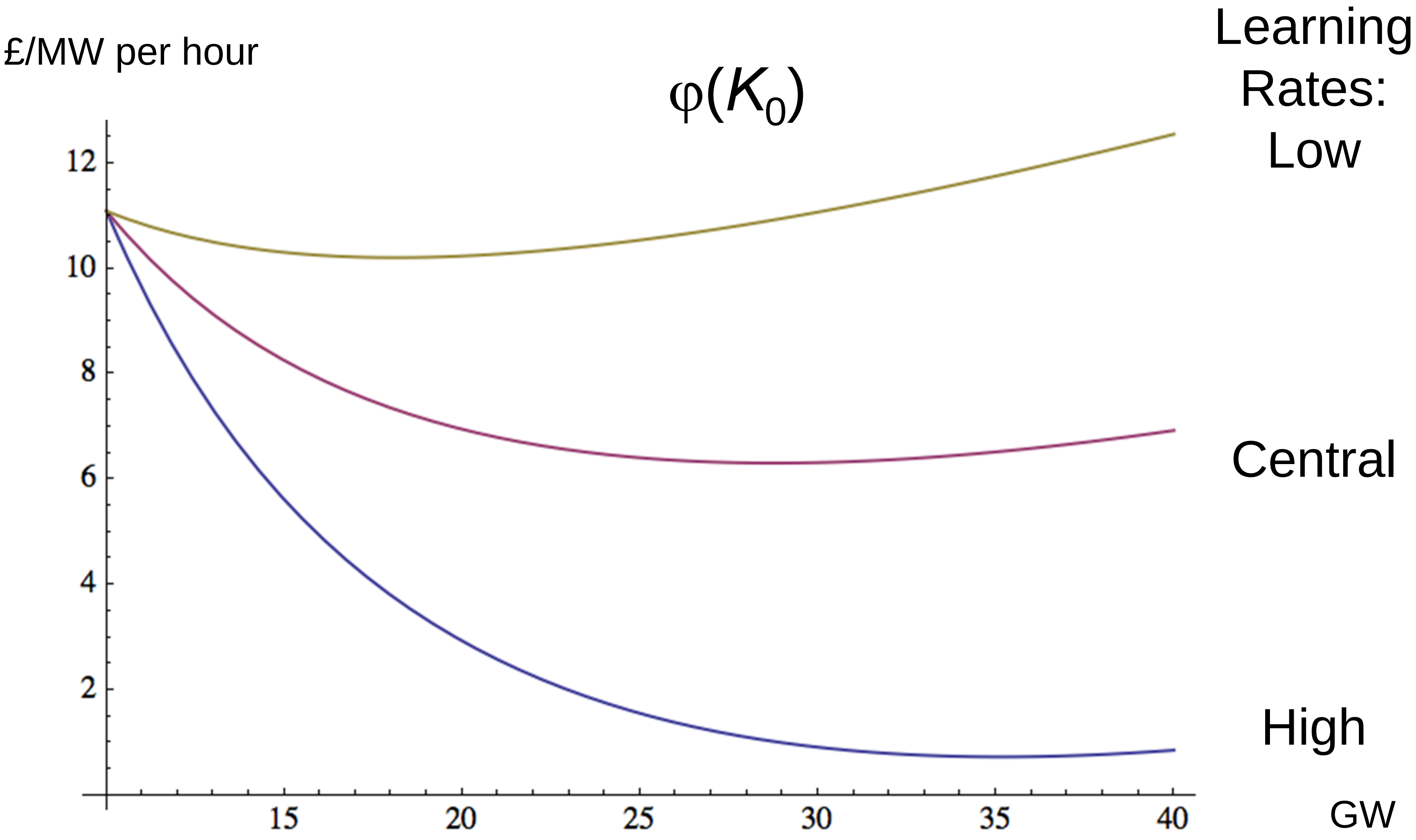
Application to the UK power market

- Capital cost of renewable (composite onshore and offshore wind) capacity with learning rate β

$$r_0(K_0) = \frac{320000}{8760} \times \left(\frac{10000}{K_0}\right)^{\beta}$$

- We study three learning rates, with a cost decrease of 10%, 19% or 30% each time capacity doubles
- Plant costs for nuclear, CCGT and OCGT taken from DECC (2013) study of generation costs, including predicted future carbon taxes rising to £70/tonne
- Demand and load factor data from Green and Staffell (2013)

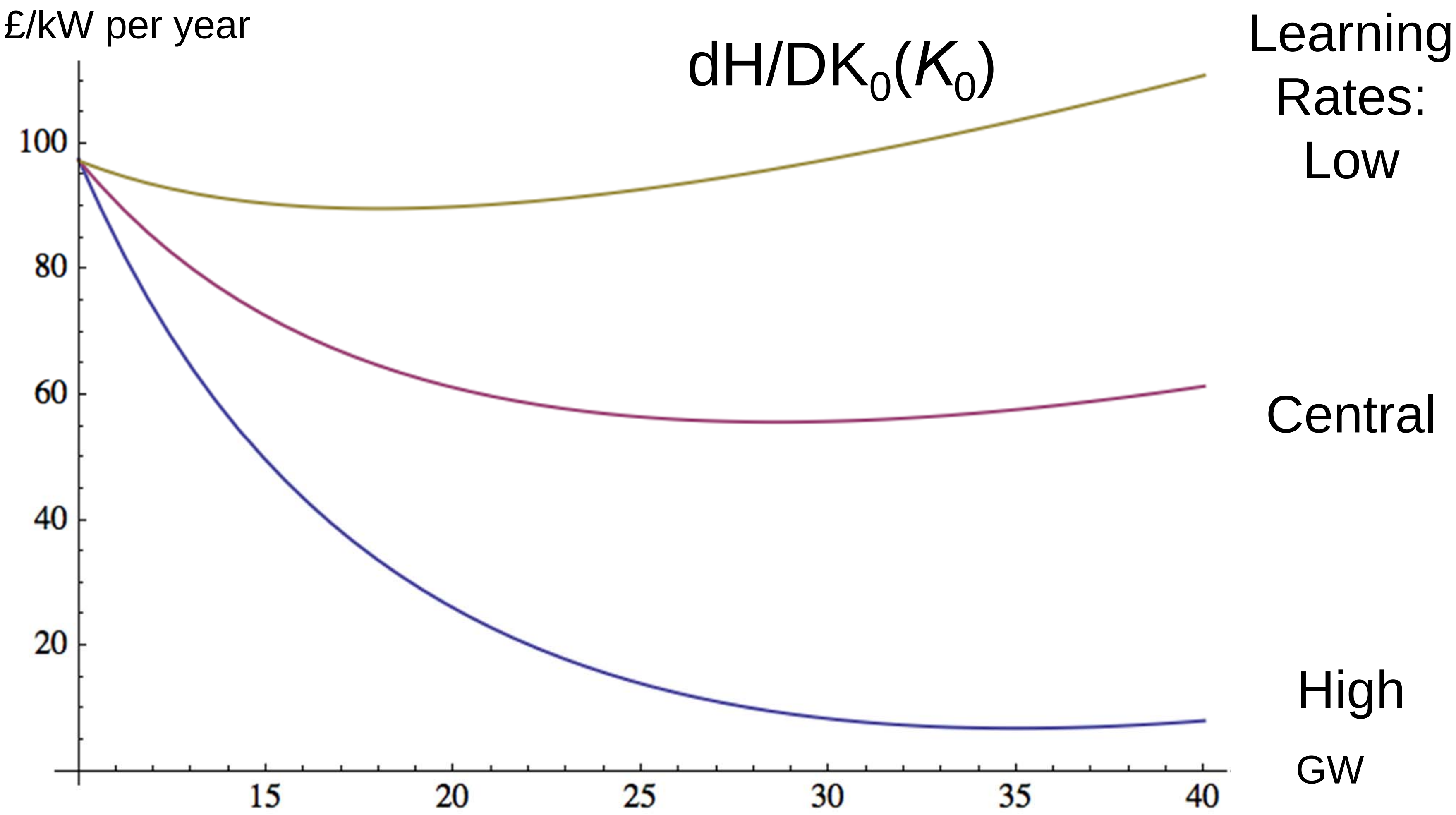
Subsidies required for all learning rates



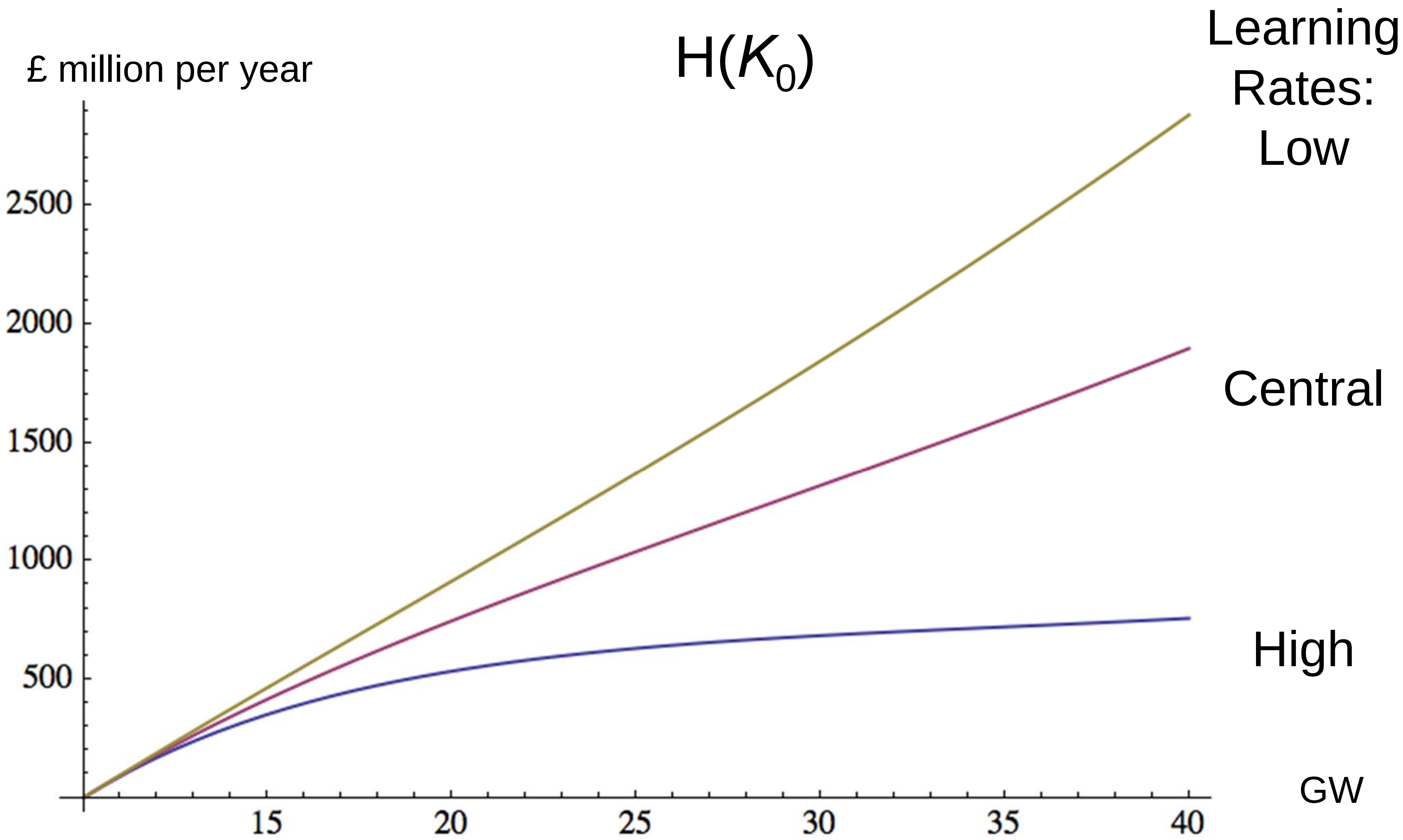
Imperial College London
BUSINESS SCHOOL

Marginal surplus loss sometimes increasing

Toulouse School of Economics



Significant cumulative surplus loss

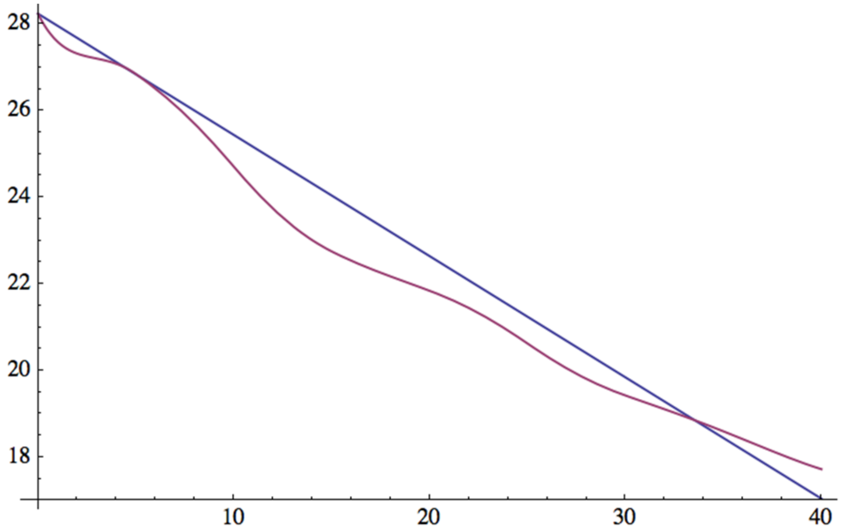


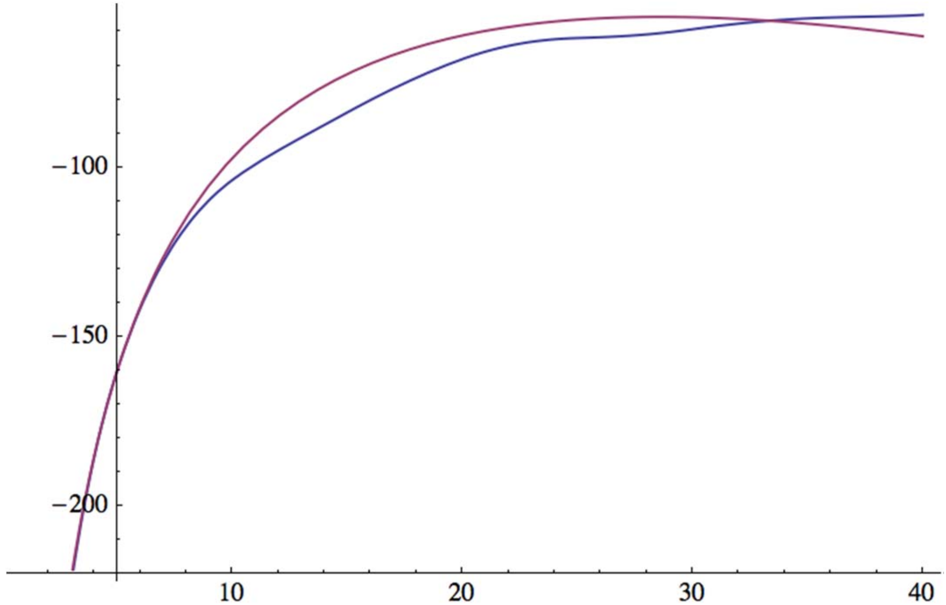
Concluding remarks

- Learning by doing should reduce feed-in tariffs as more renewable energy is installed
- The value of renewable energy falls as more is produced
- With our calibration, the second effect dominates, hence subsidies are always required
  - We measure subsidy by the difference between the FiT and the value of the energy produced
- Further work will examine the incentives created by different support mechanisms and levels of priority dispatch
- We also examine the cost of additional operating reserves required to manage renewable intermittency

Appendix

Quality of the constant variance approximation





Imperial College London
BUSINESS SCHOOL

Toulouse School of Economics