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Quantum Modelling of the Learning Curve – Dynamic Representation

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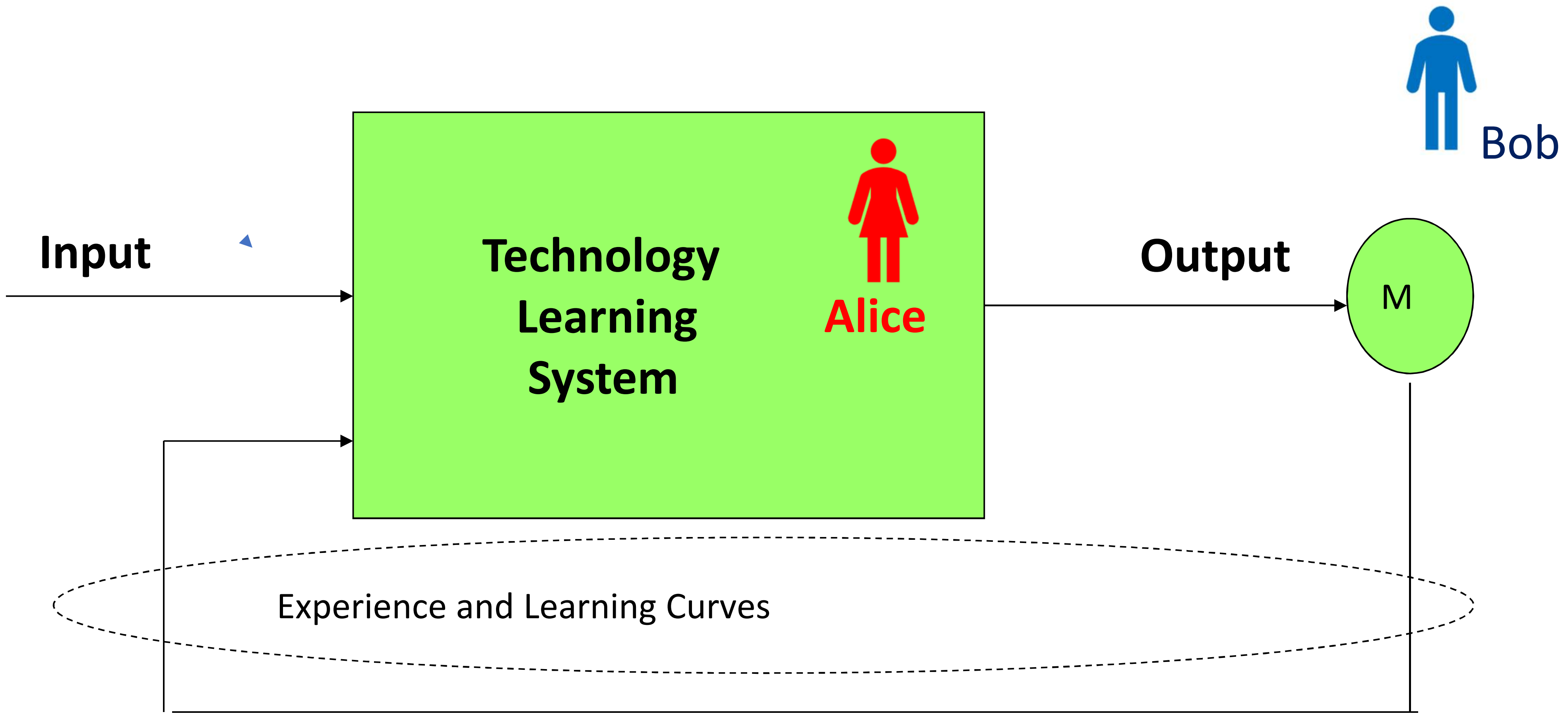
The Learning System: The different perspectives of Alice and Bob



$$P^{-1} = \text{Input/Output} = \text{const.} \times (\text{cumulative output})^{-E} = C_0 \times X^{-E}$$

$$\text{Learing Rate} = 1 - 2^{-E}$$

Learning System: fundamental challenges

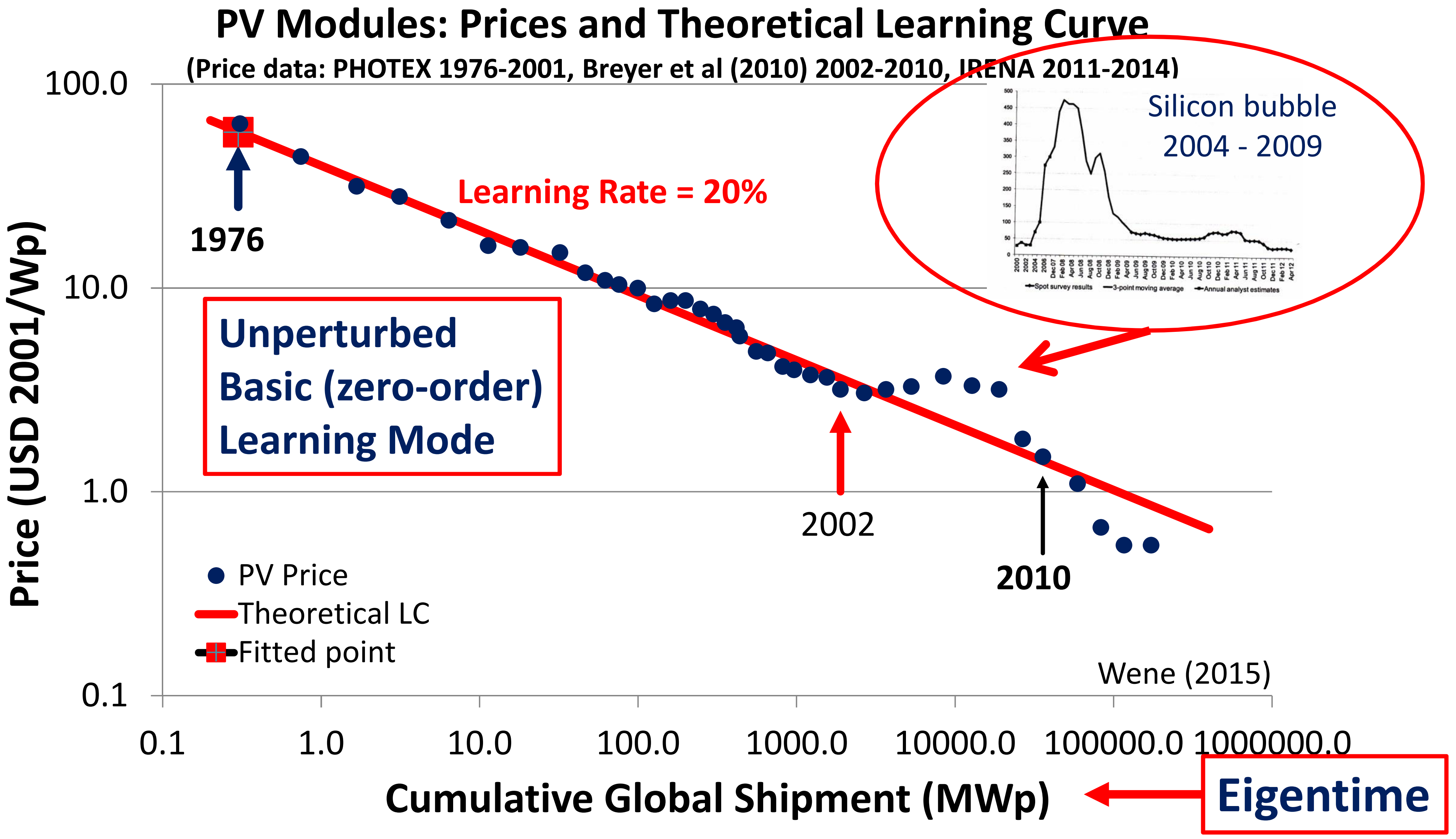
For both Observers the behaviour of the Learning System raises two fundamental challenges:

- **Entropy Challenge**: "There are no such things as self-organizing systems!" (Förster, 1959)
  The learning curve shows the Learning System continually improving performance.
  How is this allowed by the 2nd Law of Thermodynamics?

- **Cybernetic Challenge:** The system has autonomy. It controls all its internal operations to continually improve its performance. This leads to operational closure (Maturana and Varela, 1980; Varela, 1979), which restrains the system. What is the effect on the behaviour of the system?

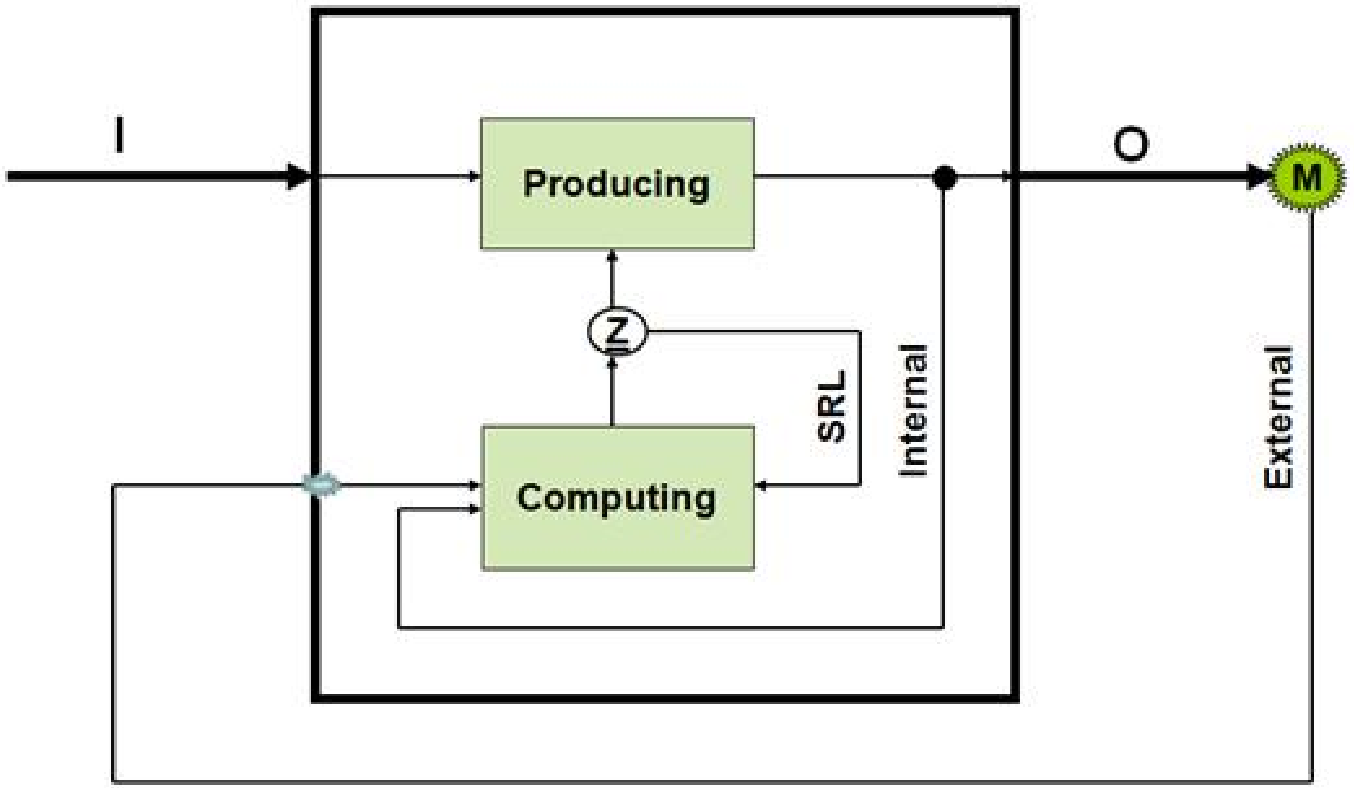
- **Alice's Solution:** *Spinor Model* for the Learning System (Wene, 2018; 2007; 2010)
  - Non-equilibrium thermodynamics (Onsager, 1931; Prigogine, 1980)
  - Quantum theory: Eigenbehaviour, superposition (Förster, 1984; Varela, 1984)
  - Learning curve for unperturbed case with one (1) constant to be fitted to data
    (i.e., Spinor Model gives shape and spectrum of learning rates; LR basic zero mode is 20%)

Spinor Model providing the learning curve for PV modules



Elements of the Spinor Model

Alice's view:
The learning system as a nontrivial machine (Wene 2007)



Non-eq. TD (Wene 2013)

$dS = d_eS + d_iS \qquad dS \geq 0$

$d_eS = - d_iS \qquad d_iS > 0$

At market equilibrium:
Learning curve result of market force keeping entropy production at minimum

Quantum Theory (Wene 2018)

$|LS> = 2^{-1/2} \begin{bmatrix} i \\ 1 \end{bmatrix} \Rightarrow \rho_{LS} = 2^{-1} \begin{bmatrix} 1 & i \\ -i & 1 \end{bmatrix}$

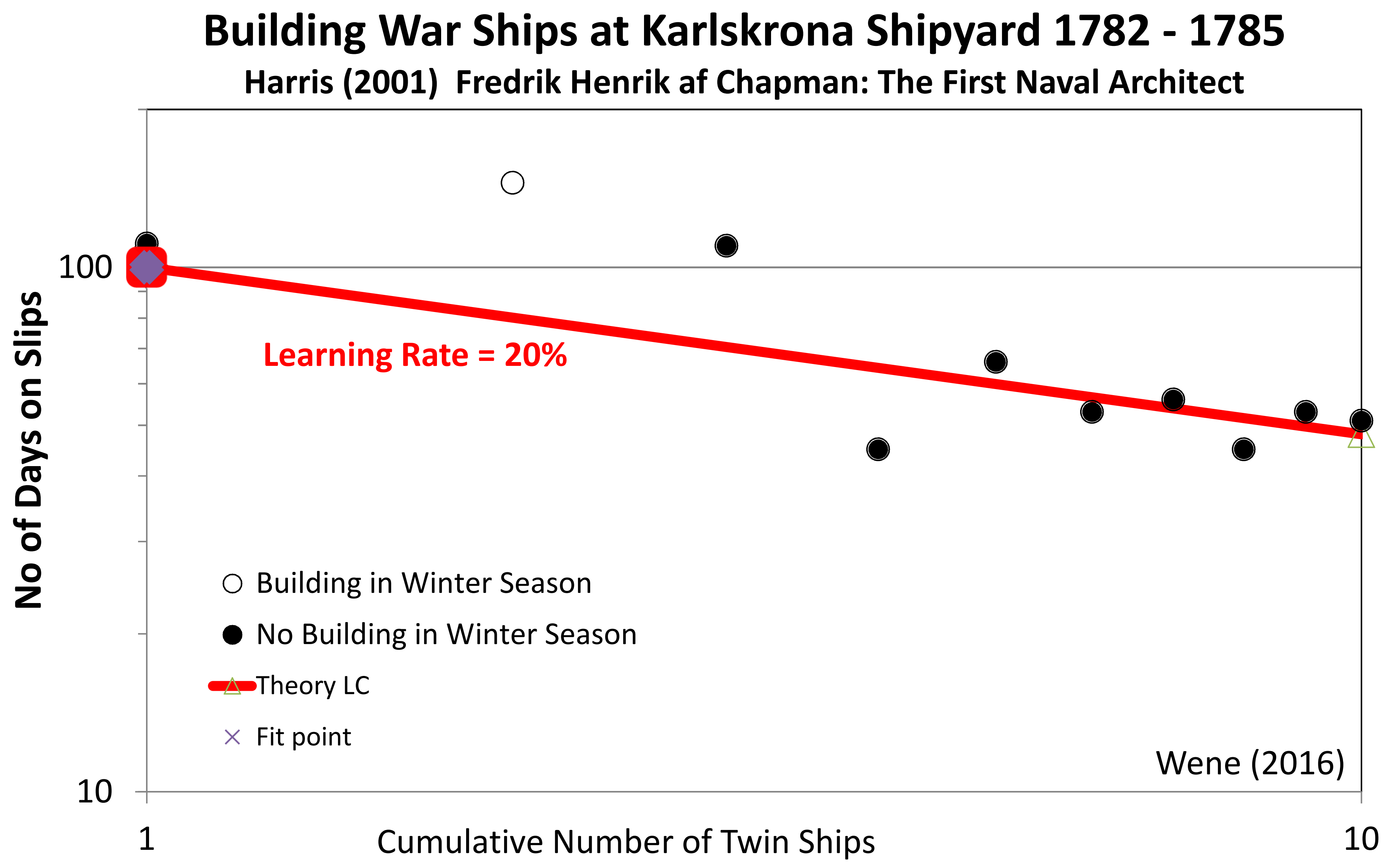
$$-2 \cdot \frac{\partial \varphi}{\partial \tau} = \rho_{LS} \cdot \varphi$$

$\varphi_1 = N_1 \cdot e^{-\tau/2}$

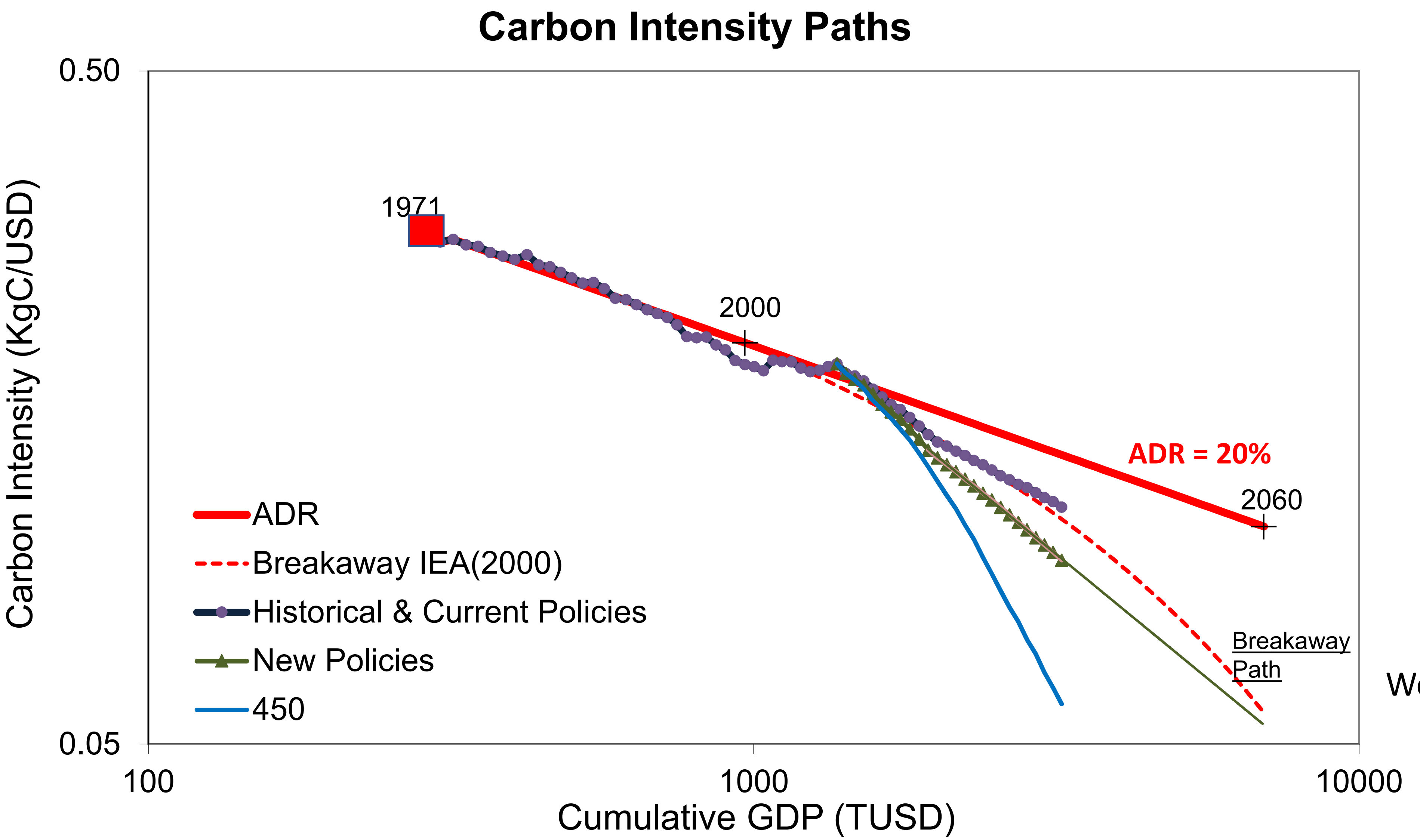
In basic zero mode: $\tau = \ln(X(t)/\pi$

$P^{-1} = C_0 \cdot X(t)^{-1/\pi}$

Finding the optimal learning: a 230 year old learning curve



A tough task for global learning: Decarbonisation of industrial activities on global scale



Wene (2011)

Thank You !

More reading

Wene, C.-O, (2016), “Future energy system development depends on past learning opportunities” *WIREs Energy Environ* Vol 5:1, pp. 16–32, doi: 10.1002/wene.172.

Wene, C.-O. (2018), “Quantum Modelling of the Learning Curve”, *Futures (2018),* https://doi.org/10.1016/j.futures.2018.02.003