Quantum Modelling of the Learning Curve
– Dynamic Representation

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The Learning System: The different perspectives of Alice and Bob

Input → Technology Learning System → Output

Experience and Learning Curves

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

Learning Rate = 1 - 2^{-E}
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

**PV Modules: Prices and Theoretical Learning Curve**


Learning Rate = 20%

Unperturbed Basic (zero-order) Learning Mode

Silicon bubble 2004 - 2009

Wene (2015)
Elements of the Spinor Model

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

Non-eq. TD (Wene 2013)
\[ dS = d_e S + d_i S \quad dS \geq 0 \]
\[ d_e S = -d_i S \quad d_i S > 0 \]

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

Quantum Theory (Wene 2018)
\[ |LS> = 2^{-1/2} \begin{bmatrix} i \\ 1 \end{bmatrix} \quad \rho_{LS} = 2^{-1} \begin{bmatrix} 1 & i \\ -i & 1 \end{bmatrix} \]

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

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

In basic zero mode:
\[ \tau = \ln \left( \frac{X(t)}{\pi} \right) \]
\[ P^{-1} = C_0 \cdot X(t)^{-1/\pi} \]
Building War Ships at Karlskrona Shipyard 1782 - 1785

Harris (2001) Fredrik Henrik af Chapman: The First Naval Architect

Learning Rate = 20%

No Building in Winter Season

Wene (2016)
A tough task for global learning: Decarbonisation of industrial activities on global scale

**Carbon Intensity Paths**

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**ADR**


**Historical & Current Policies**

**New Policies**

**450**

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Wene (2011)
Thank You!

More reading
Wene, C.-O, (2016), “Future energy system development depends on past learning opportunities”  
https://doi.org/10.1016/j.futures.2018.02.003