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ADAPTATION IN TECHNOLOGY LEARNING SYSTEMS

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SUMMARY OF ABSTRACT
The major finding of the cybernetic approach to technology learning is the 20% learning rate characterizing the eigenbehaviour of the learning system in its ground state. This paper explores mechanisms by which the system can adapt to external perturbations and pressures. The ability to adapt, the system's *plasticity*, explains deviations from the 20% rule.

ABSTRACT
As market actors in the whole chain from technology producer to technology operator and user accumulate experience, both cost and technical performance of the technology improves. This process is referred to as *technology learning*. *Experience curves* and *learning curves* measure the results of the process.
Recent high-level policy documents embrace the insights from experience and learning curves into the crucial role of technology learning and market deployment (IEA 2006, 2008; Stern, 2006; EESC, 2009). However, they also point to the large uncertainties in future estimates of learning and that these uncertainties translates into large uncertainties about the resources or learning investments needed to bring the new technologies to break-even with incumbent, high-carbon technologies. A key criticism is that the curves appear to express purely empirical relations between cost, price, or technical performance and cumulative production or use. Theoretical grounding is needed to explain observed learning rates, limit uncertainties in extrapolations and legitimize government deployment programmes.
The purpose of the project reported here is to ground technology learning in fundamental cybernetic theory and explain observations in cybernetic concepts. Technology learning is seen as the *eigenbehaviour* (Varela, 1979, 1984; von Förster, 1984, 1993) of an operationally closed system producing for a competitive market. The system is open to material and energy flows, however, the network of internal operations closes on itself. The system forms and controls all its operations. The closure theorem of cybernetics can be phrased: *In every operationally closed system there arise Eigenbehaviours.*
Wene (2007, 2008a, b) calculated the eigenbehaviours for the technology learning system assuming a pure technology and equilibrium market conditions and compared the theoretical results to observations on distributions of learning rates. Learning rates are given by the equation

$$LR(n) = 1 - 2^{\{-1/[(2n+1)\cdot\pi]\}} \qquad \text{for } n = 1, 2, 3, \ldots..$$
$$LR(0, 1, 2) = 20\%, 7\%, 4\%$$

The purpose of this paper is to extend the cybernetic approach by looking at mechanisms by which the learning system can adapt to perturbations in the markets and from government R&D programmes.
Three mechanisms for adaptation are identified:

- *Switching eigenbehaviour*, i.e., searching a higher learning mode than LR(0), is one way for the system to adapt to perturbations that do not come from input or output markets. Examples of such external **f**eatures, **e**vents or **p**rocesses (FEP) are licensing procedures and environmental regulations, which may result in considerable design

modifications. Nuclear and coal power plants are typical technologies exposed to these types of FEPs. Other important FEPs are government R&D programmes. The purpose of these programmes is to produce knowledge to increase learning, but systemically this knowledge represents external FEPs aimed at disturbing the internal network of operations. Radical innovation force important rethinking or second loop learning leading to swift cost reductions and improvements in efficiency. But FEPs representing series of minor improvements may overtax the systems absorption ability and leave it in a higher learning mode.

- *Double closure.* The system closes over internal production and over its output markets. Such a double-closed system has the ability to reprogram itself that is to change its eigenbehaviour without compromising its operational closure (von Förster, 1974, 1993; Baecker, 1996). Internal self-regulation through double closure is the preferred way for the system to adapt to perturbations on output markets. This mechanism explains the observed dispersion of learning rates around the eigenbehaviours and also provides insights into the asymmetry towards lower learning rates.
- *Disguising as trivial machine*. This mechanism provides adaptation to disturbances in input, i.e., in production factors and their markets. Supplementing the previous cybernetic analysis with a control theoretic analysis becomes interesting when there are large relative price movements in the production factor markets, e.g., due to large scarcity cost for silicon ingots for solar cells. The system can adapt by reducing the open-loop gain, absorbing some of the price movements. To an observer the system appears controlled by the open-loop and feed-back transfer functions, it has adapted by disguising itself as a trivial machine at least for a while. An important question is what happens to technology learning under this disguise.

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REFERENCES

1. Baecker, D. (1996), "A Note on Composition", *Systems Research*, Vol 13, No 3, pp 195-204
2. EESC (2009), "Towards an Eco-Efficient Economy – Transforming the economic crisis into an opportunity to pave the way for a new energy era", Exploratory Opinion of the European Economic and Social Committee, TEN/398-CESE 1700/2009, Brussels, 5 November 2009.
3. IEA (2006), *Energy Technology Perspectives 2006 – In support of the G8 Plan of Action, Scenarios and Strategies to 2050*, International Energy Agency/Organisation for Economic Co-operation and Development, Paris
4. IEA (2008), *Energy Technology Perspectives 2008 – In support of the G8 Plan of Action, Scenarios and Strategies to 2050*, International Energy Agency/Organisation for Economic Co-operation and Development, Paris
5. Stern, N. (2006), *The Economics of Climate Change - The Stern Review*, Cambridge University Press, Cambridge
6. Varela, F. (1979), *Principles of Biological Autonomy*, Elsevier-North Holland, New York.
7. Varela, F. (1984), "Two Principles for Self-Organization", in: H. Ulrich and J.B. Probst (eds.), *Self-Organization and Management of Social Systems*, p.25-32, Springer, Berlin.
8. von Förster, H. (1984), "Principles of self-organization: in a social-managerial context", in: H. Ulrich and J.B. Probst (eds.), *Self-Organization and Management of Social Systems*, p.2-24, Springer, Berlin.
9. von Förster, H. (1993), "For Niklas Luhmann: How Recursive is Communication?", in: *Teoria Soziobiologica* 2/93, Franco Angeli, Milan (reprinted in: von Förster, H., *Understanding Understanding*, Springer, N.Y., Berlin, Heidelberg, 2003).
10. Wene, C.-O. (2007), 'Technology Learning Systems as Non-Trivial Machines', *Kybernetes,* Vol. 36, No. 3/4, p. 348-363.
11. Wene, C.-O. (2008a), "A Cybernetic Perspective on Technology Learning", in: T.J. Foxon, J. Köhler and C. Oughton (eds,*) Innovations for a Low Carbon Economy: Economic, Institutional and Management Approaches*, Edward Elgar, Cheltenham..
12. Wene, C.-O. (2008b), "Energy Technology Learning through deployment in competitive markets", *The Engineering Economist*, Vol. 53, No. 4, pp. 340-364.