A stock price model for technology learning in energy systems modelling

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We use a stochastic approach for energy technology learning

• Long-term simulations of environmental, energy and transport systems typically rely on strong, deterministic assumptions about the pace of learning-by-doing and learning-by-R&D among environmentally friendly technologies

• In reality, the future evolution of technical and cost parameters is highly uncertain

• This paper develops a stochastic approach for modelling uncertain energy technology innovation

• Focus is on innovations that lead to a reduction in investment cost of a technology, i.e. the cost per kW to install capacity of the technology

• The model is applied using JRC-EU-TIMES, a model of the European energy system, from the TIMES-MARKAL family

• Our final objective is to determine the value of innovation
We apply a stock pricing model to energy technology costs

- Recent literature has extensively addressed the issue of technological uncertainty in models of the energy system and climate change, e.g.:
  - Baker and Solak, 2011
  - Blanford, 2009
  - Bosetti and Drouet, 2005
  - Goeschl and Perino, 2009
- The use of financial mathematics for the purpose of addressing innovation is already present in e.g. Grenadier and Weiss, 1997

- This paper takes a different angle: we use a **stock pricing model** to describe technology learning

- Their work is focused on the optimal investment strategy for a firm. In our paper, by contrast, we focus on the **societal value of innovation**
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**Deterministic value of technology innovation in energy models**

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We value energy technology innovation based on energy system cost

- We study the **value of energy technology innovation** in the context of an **optimisation model** of the energy system.
- Energy technology **innovation** is assumed to be represented by a **cost decrease in the investment cost** of a particular energy technology, such as solar power.
- The key **metric** used to evaluate energy technology innovation in this paper is the impact of such a cost decrease on the **total discounted cost of the energy system** (simply named **system cost** in the remainder of this presentation).
Innovation has a non-linear effect on system cost

**System cost**
Billion EUR

When solar costs are higher, less solar will be built, hence system cost does not evolve linearly with solar investment costs.

When solar costs are lower, more solar will be built, hence system cost does not evolve linearly with solar investment costs.

*This can be computed without rerunning the model*
The value of innovation may be underestimated when the non-linearity is not considered.

Potential underestimation of value of innovation, if you do not rerun the model and instead use a linear approximation.

Value of innovation: reduction in system cost due to additional innovation.

Specific investment cost of e.g. solar PV EUR / kW.
Numerical simulations are conducted using the JRC-EU-TIMES model

- The JRC-EU-TIMES model is a model of the EU energy system based on the TIMES model generator (Loulou et al., 2005).
- The TIMES model generator is developed and used by the Energy Technology Systems Analysis Programme (ETSAP), an implementing agreement of the International Energy Agency. TIMES (The Integrated MARKAL-EFOM System) is an economic model generator for local, national or multi-regional energy systems which provides a technology-rich basis for estimating the development of the energy system over a long-term time horizon.
- The JRC EU TIMES model is a model of the entire EU energy system, with disaggregation to all EU Member States. The JRC-EU-TIMES model is similar to the Pan-European TIMES model (PET) developed for the NEEDS and RES2020 projects funded by EU research programmes and (see Giannakidis et al., 2009).
Non-linearity of technology cost impact seems quite limited in a deterministic run of JRC-EU-TIMES

System cost (NPV, PET Oct 2012, P5-2050, with CO₂ trade), Mn EUR

- The non-linearity of system cost changes as a function of technology cost changes is limited. Even at the edges the difference in changes between linear and non-linear is only:
  - 16% for wind
  - 3-4% for solar

- In the stochastic setting in the remainder of this paper this effect will become more important.
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The jump-diffusion model from stock price modelling seems appropriate for technology

- Technology parameters are similar to stock prices: they have a gradual and random evolution, with occasional large jumps (crashes in stocks, or breakthroughs in innovation)
- Hence we can use well-known models from mathematical finance

Jump-diffusion model for stock prices (Merton, 1976)

- The jump-diffusion model consists of:
  - Geometric Brownian motion (a random walk), PLUS
  - A drift, PLUS
  - Occasional jumps (random size and random interval between jumps)
- The same can be applied to specific investment costs
Application of the jump-diffusion model leads to reasonable paths for specific investment costs

Assumptions
- 5% annual volatility (random walk)
- Jumps with average frequency of once per 20 years
- Only negative jumps, average size -20%, geometric distribution (fat tails, hence large jumps not unlikely)
- As a compensation: 1% upward drift per year, so that on average the end point is the same as without jumps
- This process is multiplied with the deterministic cost paths in JRC-EU-TIMES

Sample paths for e.g. Wind onshore
EUR / kW
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The stochastic technology cost paths can be run with the JRC-EU-TIMES model

- The jump-diffusion model is applied to Wind (all technologies) and Solar (all technologies) at the same time.
- For the sake of simplicity, correlation among Wind technologies and among Solar technologies is assumed to be 1. Correlation between Wind and Solar is assumed to be 0. All this can be easily adapted.
- 33 runs are performed.
- The aim is to fine-tune our estimates of the impact of innovation, by considering a wide range of learning scenarios, including breakthroughs.
- Due to slight non-linearity of system cost as a function of technology cost, breakthroughs can be expected to lead to a larger value of innovation.
Results from running JRC-EU-TIMES with stochastic technology costs: effect of wind costs 2020

System cost (NPV, JRC-EU-TIMES, P5-2050, with CO₂ trade), Mn EUR

- The stochastic results are steeper and more curved than the deterministic results, because there may be breakthroughs between 2020 and 2050.
- As a result, the value of innovation may be higher.

*Compared to baseline
Results from running JRC-EU-TIMES with stochastic technology costs: effect of solar costs 2020

System cost (NPV, JRC-EU-TIMES, P5-2050, with CO₂ trade), Mn EUR

- The results are even more pronounced for solar energy, because it is a smaller technology, hence the effect of break-throughs is larger.

*Compared to baseline
Without stochastics, the value of innovation may be significantly underestimated

- **Wind:**
  - The value of a 20% deterministic decrease in cost by 2020 and permanent thereafter, is ...  
  - The expected value of a 20% stochastic decrease by 2020 (with stochastic evolution before and after), is ...

- **Solar:**
  - The value of a 20% deterministic decrease in cost by 2020 and permanent thereafter, is ...
  - The expected value of a 20% stochastic decrease by 2020 (with stochastic evolution before and after), is ...

- Without the stochastic approach the value of innovation would be understated by up to a factor 3
- This is an example of the **portfolio diversification** effect

<table>
<thead>
<tr>
<th>Wind Deterministic Decrease</th>
<th>Wind Stochastic Decrease</th>
<th>Solar Deterministic Decrease</th>
<th>Solar Stochastic Decrease</th>
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<tbody>
<tr>
<td>16.1 bn EUR</td>
<td>21.1 bn EUR</td>
<td>3.1 bn EUR</td>
<td>9.7 bn EUR</td>
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Conclusions

- This paper applies a stochastic jump-diffusion stock pricing model to the technology learning process in energy system models.

- Using a Monte Carlo simulation with the JRC EU TIMES model, it is shown that stochastic modelling can capture the non-linear benefits of energy technology breakthroughs, which are ignored in deterministic simulations that consider only an average technology innovation scenario.

- In a simplified example with stochastic wind power and solar power investment costs, it is shown that the deterministic simulation may underestimate the value of solar power innovation by a factor 3.
Thank you!

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- Any interpretations or opinions contained in this paper are those of the author and do not necessarily represent the view of the European Commission.
References

Appendix
TIMES Stochastic: Pros and cons

Pro

- Analysis until now was non-adaptive: although many paths are considered, each individual path is run under perfect foresight. Using TIMES Stochastic, the investment decisions can be made **adaptive**, and **hedging** is possible.

Con

- **Computational complexity**: every stochastic event multiplies the number of variables, and hence the computational complexity.

- The number of stochastic events is limited, hence there is a limit to the number of technologies and time steps with stochastic events.
TIMES Stochastic: Concept is simple ...

- Uncertainty is modelled through an event tree
- The optimiser makes decisions that minimise the expected system cost
... but computation is very intensive

- All scenarios are solved at the same time
- There are constraints so that decisions cannot diverge before uncertainty is resolved
TIMES Stochastic: Possible implementation

• TIMES Stochastic allows 64 scenarios, i.e. 6 splits of the tree into 2 branches. This means that we can consider:
  ▪ 1 technology with stochastic evolution at 6 points in time
  ▪ 2 technologies with stochastic evolution at 3 points in time
  ▪ 3 technologies with stochastic evolution at 2 points in time
  ▪ 6 technologies with stochastic evolution at 1 point in time

• We can sample the stochastic paths of technology costs, and convert them to an event tree (as is also done in stock option pricing with e.g. the discretisation of the geometric Brownian motion).

• The resulting model is likely to be very hard to solve. An additional implementation difficulty is that there is little documentation on how to do this in VEDA, although it is probably not so hard since TIMES itself is very well documented.