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A system dynamics approach for modelling a lead-market-based export potential

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Abstract

For knowledge-intensive goods, foreign trade performance also depends on the quality of the technology. Important factors to consider are technological capabilities, various market factors which influence the chances of a country developing a lead-market position, innovation-friendly regulation and the existence of internationally competitive complementary industry clusters. In order to model these aspects, various feedback mechanisms between these factors have to be taken into account, among them knowledge spillovers from the export success which lead to an erosion of a lead-market position over time. A system dynamics framework is used for a first implementation of a simulation model for wind energy technology exports from Germany. The empirical results show the expected dynamics of the system and underline the importance of the various feedback loops.

Keywords:

Renewable energy technologies, exports, first-mover advantage, lead markets

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1 Introduction

The idea of realising first-mover advantages by developing lead markets has become very prominent in the justifications of technology and innovation policies. This holds also for renewable energy technologies, which are targeted by the Lead Market Initiative of the European Union [1].

Lead markets denote the country in which a later globally successful innovation takes off [2]. The rationale of countries to support lead markets developing in their countries is linked to the notion of first-mover advantages in foreign trade: it is argued that the trade patterns for technologies are also determined by the quality of the technology and its innovative character. Thus, high international market shares depend on the innovation ability and the achieved learning effects. If a country forges ahead in renewable energy, it tends to specialise early in the supply of the necessary technologies. Given the growing demand for energy, on the one hand, and the pressure to push for non-fossil fuels on the other, a subsequent expansion in the international demand for these technologies can be foreseen. According to the logic of a first-mover advantage, these countries are then in a good position to dominate international competition due to their early specialisation in this field [3]; [4].

Macroeconomic scenario analyses show that additional exports are one key for positive employment effects of national policies increasing the use of renewable energy [5]; [6]. However, these analyses use only ad hoc assumptions on the export potential which are used as exogenous data input in the models. Improving the reliability of these results requires that the effect of these policies on exports can be quantified. Thus, a more disaggregated analysis on the meso level is required. Especially in this field, new ways of implementing modelling approaches based on evolutionary economic thinking have recently been called for [7]; [8].

In this paper an approach is developed as to how to model the lead market based export potential empirically. The paper concentrates on the background of implementing such a model, but also presents first empirical results. It concentrates on wind energy technologies and modelling the market shares of Germany versus the rest of the world. In the first part of the paper, the factors which are important for exploiting a first-mover advantage are presented. In the second part of the paper, the concept for a pragmatic modelling approach is presented, based on a system dynamics framework. The third part of the paper describes the experience in implementing such a model for the case of exports

of wind energy technologies from Germany. The paper concludes with a critical reflection of the modelling exercise and suggestions for future research.

2 Lead-market-based factors for a first-mover advantage

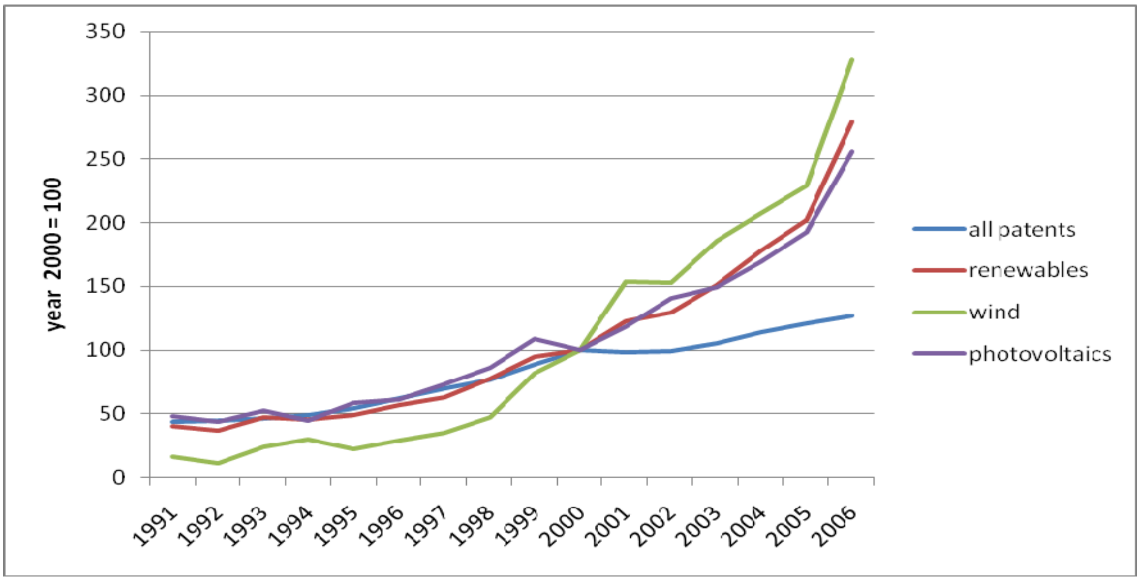
For first-mover advantages to be realised, the domestic suppliers of renewable energy technologies have to be competitive internationally so that they - and not foreign suppliers - meet the demand [9]. Taking the globalisation of markets into account, this requires establishing competence clusters which are difficult to transfer to other countries with lower production costs. These competence clusters must consist of high technological capabilities linked to a demand which is open to new innovations and horizontally and vertically integrated production structures [10]. The following factors have to be taken into account when assessing the potential of countries to benefit from a first-mover advantage:

- Characteristics of the technology which form obstacles to international relocation,
- demand conditions in the country,
- innovation-friendly regulation in the country,
- technological capability of the country,
- competitiveness of related industry clusters in the country

A first-mover advantage requires that competition is driven not so much by cost differentials and the resulting attractiveness of international production location alone, but also by quality aspects. The evolutionary-institutional economics of technical change underlines that knowledge always has tacit components, which makes the acquisition of capabilities in the relocation of knowledge-intensive production more difficult [11]; [12]. Thus, especially goods which can be characterised as knowledge-intensive can form the basis for long-lasting first-mover advantages. Empirical results indicate that under these conditions, unit labour costs play a lower role in determining exports [13]; [14]. However, knowledge is necessary not only to create, but also to maintain export advantages [15]. Thus, high innovation dynamics and high potential learning effects of the technology are working against cost-driven relocation of production facilities. Otherwise an erosion of the importance of the quality component of the technology would take place, which in line with the Product Cycle Theory of Vernon [16] or the seminal works of Krugman [17] or Helpman/Grosman [18] would be equivalent to no longer climbing up the quality ladder and would lead to a subsequent relocation of production facilities towards imitating countries with lower production costs.

In general, the technology intensity of renewable energy technologies can be judged as being above average or even (e.g. photovoltaics) high-tech [19]. This is is supported by the results of Amable/Verspagen [13], which show that electrical machinery belongs to the sectors with competition driven strongly by innovation. Especially wind energy technologies have experienced constant technological upgrading, which is most prevalent in the increasing size of the turbines. An analysis of various technology forecasts, e.g. the Japanese Delphi study [20], reveals that higher than average learning effects are expected for renewable energy technologies. Furthermore, the patent dynamics for renewable energy are also impressive. This holds especially for wind energy, which has substantially higher growth rates in transnational patents than the average increase in patents [21]. Thus, competition in wind energy technologies is driven strongly by quality aspects.

Figure 1: Patent dynamics for renewable energy technologies



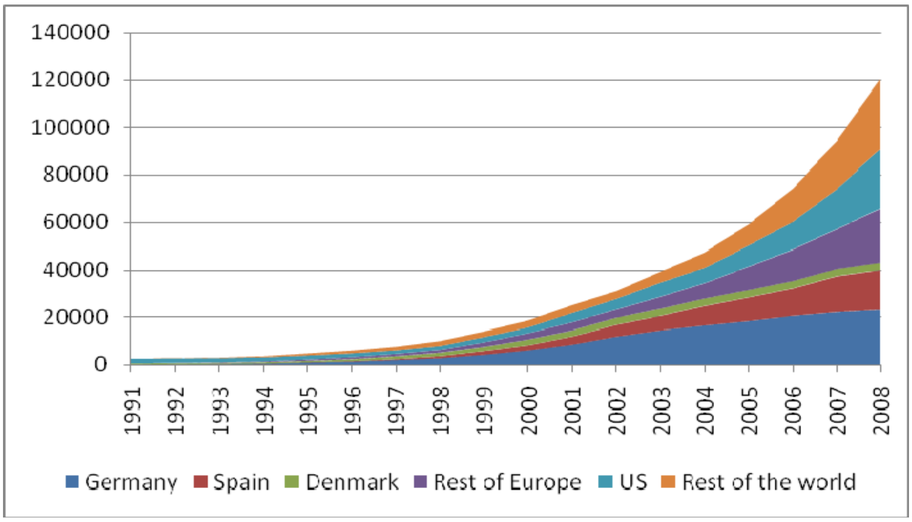
Source: data based on ISI lead market database [21]

The importance of the demand side can be traced to the work of Linder [68], and is emphasised by authors such as von Hippel [22], Porter [23] or Dosi et al. [24]. There are various market factors which influence the chances of a country developing a lead-market position. Beise [2] classifies them in the 5 categories demand and price advantage, market structure, and transfer and export advantage.

In general, a growing demand oriented towards innovations and readily supporting new technological solutions benefits a country in developing a lead-market position. Another factor is a market structure which facilitates competition. The export and transfer advantages are difficult to assess with indicators. However, it can be assumed that already existing export success, especially in complementary technologies also backs these two factors. The price advantage of countries is also very important. Clearly it benefits countries which increase their demand fastest and thus are most able to realise economies of scale and learning by user-producer interaction.

European countries have been forging ahead in the diffusion of wind energy until recently. Furthermore, the political goals for the EU will bolster this advantage in future. Nevertheless, there are also other countries which have increased their diffusion rates in the last 2 years, especially the U.S., China and India. If the demand in these large markets continues to increase, this will cause a huge rise in absolute numbers which might strengthen the price advantage of the companies supplying these markets.

Figure 2: Diffusion of wind energy in MW for selected countries and regions



Source: data from European Wind Energy Association

A consistent lead market situation must also be supported by innovation-friendly regulation [25]; [26]. Thus, the comparative advantage in innovation-friendly national regulation becomes another factor for sustaining first-mover advantages. This is especially true for sustainability innovations in infrastructure fields such as energy, water or transportation, which are characterised by monopolistic bottlenecks. In these fields, the innovation-friendliness of the general regulatory regime, e.g. with regard to IPR or the supply of venture capital, must not only be accompanied by an innovation-friendly environmental regulation, but also by an economic sector regulation resulting in a triple regulatory challenge [27].

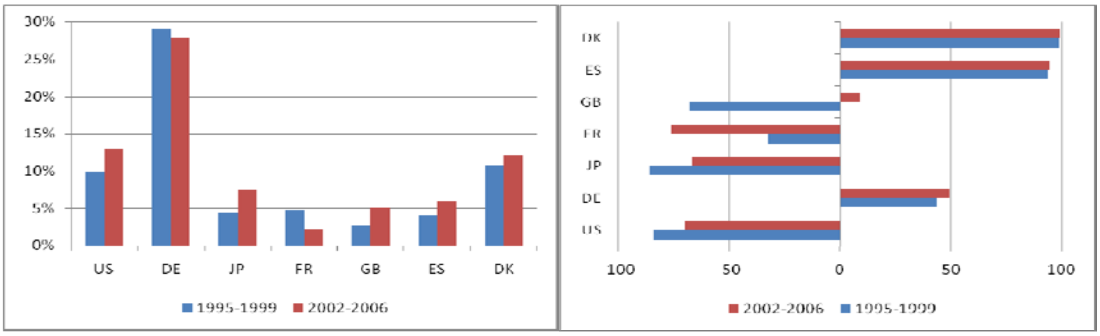
The policies to foster renewable energies have been evaluated in numerous case studies (see [28]; [29]; [30]; [31]; [32]; [33]; [34]; [35]; [36]; [37]; [38]; [39]; [40]; [41]). Increasingly they use a sectoral or technological system of innovation approach as heuristic. The essence of these studies is twofold: first, fixed feed-in tariffs offer advantages over other policy instruments because they are tailored to the needs of new entrants into the markets, which are characterised by specific problems of uncertainty and refinancing. Second, soft context factors such as the long-term character of political goals for renewable energy are important for the innovation effects. Even the comparative importance of green policies for voters are seen as important, which are key supportive context factors for the legitimacy of a technology which is highlighted as an important function for additional innovations [27]; [41]; [42]); [70].

Since the Leontief Paradox and subsequent theories such as the Technology Gap Theory, it has become increasingly accepted that international trade performance depends on technological capabilities (for an overview see [43]; [44]). Thus, the ability of a country to utilize a lead market for a first-mover advantage also depends on its comparative technological capability. If a country has a comparatively high knowledge base, it also has an additional advantage in developing and marketing future technologies.

Despite all the problems and caveats associated with measuring technological capabilities, indicators on R&D expenditures and patent indicators such as share of patents or the relative patent advantage are among the most widely used indicators. The empirical importance of these indicators for trade patterns, which was already concluded in the 1980s ([45]; [43]), is also supported by more recent empirical research ([13]; [46]; [47] and [14]; [48]; [49]; [50]; [51]; [15]). Madsen [52] underlines the importance especially of transnational patents. In the case of wind energy technologies, the data for transnational patents clearly shows that 3 countries – Denmark and Spain, followed by Germany – have specialised the most in wind energy. In absolute terms, Germany leads in patent shares. There have been no major changes in the last 10 years, however a slow increase can be observed in the U.S. Japan and UK lately.

It is widely held that innovation and economic success also depend on how a specific technology is embedded into other relevant industry clusters. Learning effects, expectations of the users of the technology and knowledge spillovers are more easily realised if the flow of (tacit) knowledge is facilitated by proximity and a common knowledge of language and institutions [12]. Furthermore, there is strong empirical evidence that the international competitiveness of sectors and technologies is greatly influenced by the competitiveness of interlinked sectors [53]. Wind energy technologies generally have very close links to machinery. Thus, countries with strong production clusters in machinery have a particularly good starting point for developing a first-mover advantage for renewable energy technologies, especially because success in this sector also contributes to an export and transfer advantage.

Figure 3: Patent indicators for wind energy technologies for the most active OECD countries



Source: data from ISI lead market database [21].

The success in a specific high-tech industry also depends on the general attractiveness of the country in this field, e.g. availability of highly trained labour or venture capital. If there is such a supporting environment in a country, the obstacles for relocation of production facilities to another country are higher, and it becomes more likely that a first mover advantage can be sustained.

There are also factors which work towards the erosion of a first mover advantage. One such approach is also implied by the product cycle theory. There it is argued that the characteristics of a technology change over time, which makes the technology more easily reproducible and hence more subject to price competition. Thus, in the context of the product cycle theory, the erosion of a first-mover advantage is brought forward by a change in the characteristics of the technology.

Since the seminal paper of Grossman/Helpman [54], the importance of international knowledge spillover via trade is widely acknowledged in the literature. The mechanisms of how the trade of technologies affects knowledge spillover have been further analysed by Griliches [55] and Archibugi/Pietrobelli [12]. The knowledge embodied in patents, which are published, becomes codified and accessible. The export of technologies makes knowledge embodied in the physical technology also partially accessible to the users. Spatial proximity with the technologies facilitates user-producer communication in the importing countries. Furthermore, there is empirical evidence that the inflow of FDI and the resulting production in host countries leads to knowledge spillovers towards the host countries [56]; [57]. However, there is also evidence which supports knowledge spillovers towards the supplying companies [58]; [59], together with the effect of learning by exporting. Depending on the absorptive capacities and the emergence of competing technology providers in the importing countries, the knowledge spillovers lead to an erosion of technological leads. This erosion is further facilitated, if the importing countries start to implement also the other success factors such as innovation-friendly regulation patterns within their countries.

In the aftermath of the paper by Coe/Helpman [60], there has been mixed empirical evidence about the importance of the various channels of international knowledge spillovers [61]; [62]; [63]; [64]; [65]. However, there is also clear evidence that obstacles exist, especially for international knowledge spillover [66], which make this variable also open for policy-making towards either enhancing or reducing spillovers.

3 Lead market factors in a system dynamics framework

It is characteristic for the factors introduced above that they influence each other. Sustaining a first-mover advantage requires constantly improving the quality of technologies. Considering innovations as a process characterised by numerous feedbacks, the factors which influence the first-mover advantage are also subject to the numerous feedbacks within a successful functioning system of innovation. Thus, modelling such a system poses considerable challenges:

- the modelling approach must account for the various feedback mechanisms,
- it must be able to model the development of the various factors over time, and
- it must be flexible and must allow access to different levels of data (e.g. quantitative established relationships, but also qualitative information).

System dynamics is a modelling approach which fulfils these requirements. It is a methodology designed to improve the understanding of complex systems over time. It is widely used in management, natural sciences but also increasingly in economics. It accounts for the influence of random effects, does not necessarily lead to equilibrium solutions like traditional economic models and highlights the adaptation processes.

The core variables of system dynamics are stocks and flows, with the flows determining the levels of the stocks. Essential to this methodology is the use of time delays and feedback loops (with feedback loops being a consequence of time delays). Thus, a level variable can directly or indirectly influence itself. The system behaviour is influenced by both exogenous factors, which by definition are not affected by the system, and endogenous factors, which are modelled with various feedback mechanisms within the system. Feedback mechanisms can be either positive (the influenced variable changes in the same direction as the influencing variable) or negative (the influenced variable changes in the opposite direction to the influencing variable). The relations between the variables are modelled with mathematical functions, which can also allow for non-linear behaviour. Furthermore, the complex interplay of the various feedback mechanisms allows building complex vicious or enhancing feedback circles.

In the previous section, the factors for a first mover advantage were discussed. In order to integrate them into a system dynamic model for the export shares of country A for wind energy technologies, they are grouped into the following building blocks:

- The exports shares of country A are explained by the model.
- The market factors comprise the various demand factors, that is demand and price advantage, market structure, and transfer and export advantage.
- The patent advantage represents the technological capabilities.
- The regulation comprises the factors which can be directly influenced by policy, e.g. R&D support, diffusion of the technology, but also soft context factors such as the policy style and the long-term character of the policy.
- The competitiveness of complementary sectors to wind energy technologies.
- The obstacles to international relocation reflect the lead-market characteristics of the wind energy technologies resulting in the importance of the quality component. It is also influenced by how attractive it is to relocate due to differences in other factors of competition (e.g. availability of skilled work force).
- Spillovers refer to the knowledge which is transferred to other countries. They are induced by various mechanisms ranging from access to codified knowledge (e.g. patents) to capital embodied knowledge (e.g. import of wind energy technologies).

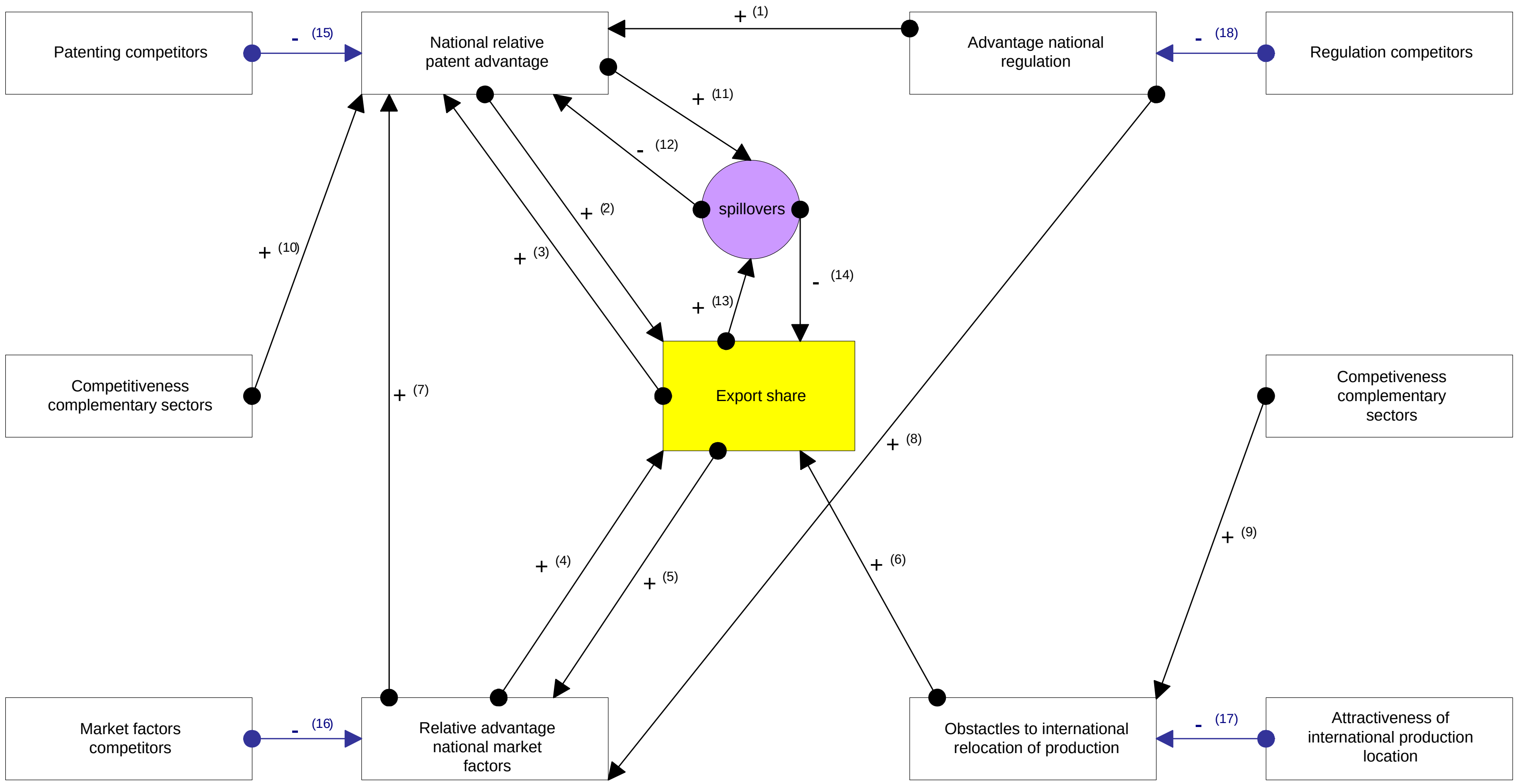
The effect on the exports of country A depends on the relative advantage of country A compared to the competing countries. The relative advantage of country A for each variable can be influenced not only by changes in the quality of the variable in country A itself, but also by changes in the competing countries. Thus, it is also necessary to account for changes in the various factors in the competing countries.

Figure 4 presents these factors and the most important feedbacks between them in a system dynamics framework. This figure summarises the previous section in a formalised way and gives a qualitative overview on the assumed influences. The numbers besides the arrows are for identification only, without ranking them. The plus or minus signs indicate a positive or negative effect of the influencing variable on the influenced variable:

1. Advantage in national regulation -> National relative patent advantage (+)
2. National relative patent advantage –> Export shares (+)
3. Export shares –> National relative patent advantage (+)
4. Relative advantage due to national market factors -> Export shares (+)
5. Export shares -> Relative advantage due to national market factors (+)
6. Obstacles to international relocation of production -> Export shares (+)
7. Relative advantage due to national market factors -> National relative patent advantage (+)

8. Advantage in national regulation -> Relative advantage due to national market factors (+)
9. Competitiveness of complementary sectors -> Obstacles to international relocation of production (+)
10. Competitiveness of complementary sectors -> National relative patent advantage (+)
11. National relative patent advantage -> Spillovers (+)
12. Spillovers -> National relative patent advantage (-)
13. Export shares -> Spillovers (+)
14. Spillovers -> Export shares (-)
15. Patenting competitors -> National relative patent advantage (-)
16. Market factors competitors -> Relative advantage due to national market factors (-)
17. Attractiveness of international production location -> Obstacles to international relocation of production (-)
18. Regulation competitors -> Advantage in national regulation (-)

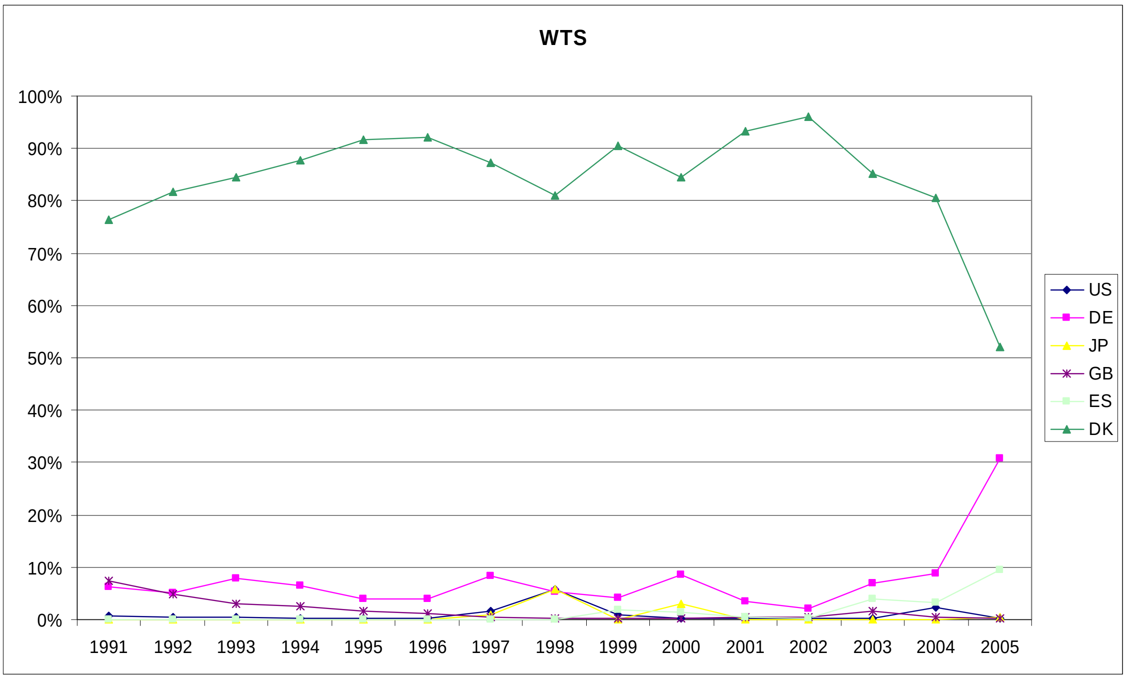
Figure 4: Conceptual model of lead-market-based foreign trade success in system dynamics methodology



4 Implementing the model and examples of empirical results for the case of exports of wind energy technologies

Wind energy technology exports have been dominated by Denmark for many years. Very recently, Germany – which has been the leading country in installed wind energy capacity - has increased its export share substantially, and future export success are used as a justification for further support for the diffusion of wind energy in Germany. Thus, the case of Germany is taken as a case study for the implementation of a system dynamics lead market model based on the logic outlined in the previous section.

Figure 5: World trade shares in wind turbines



Source: data from ISI lead market database [21]

A system dynamics model essentially consists of a set of mathematical equations, each using input data to produce a result. The factors described above have been quantified using a series of proxies for the indicators. Depending on data availability, various adjustments had to be made. In addition, the functional form of the feedback loops had to be specified. In order to limit the necessary modelling work, the model was limited to model the export shares of Germany only. However, the success in the world market depends on the relative advantage one country gains compared to the competing countries. Thus, the modelling has to account for the comparative advantage of a country with regard to the first-mover advantage factors in the other countries. Therefore some of the influences are described as relative, meaning that the relevant figure measures the situation of Germany compared to the rest of the world. Some of the influencing factors were modelled exogenously, which makes the handling of the model less complex. This is the case for the innovation-friendliness of the regulatory system, the competitiveness of the complementary sectors (machinery) and the lead-market factors in the rest of the world.

The following model structure was used to perform the model runs (see also Annex):

- The cost developments, which affect the price advantage, were modelled according to the cumulative installed capacity and the cumulative R&D spending in the countries.
- The regulation regime was quantified using R&D spending by the government as a proxy for the supply side and the diffusion of wind technology for the demand side. Additionally, “innovation-friendliness” was quantified, based on the figures from the Global Competitiveness Reports concerning how difficult it is to obtain a bank credit for a relevant project as well as the general availability of risk capital. Additionally, a qualitative analysis of the innovation-friendliness in the field of wind power technology was used, which had been developed by Walz et al. [69].
- The demand advantage is based on spending for environment protection according to OECD statistics as well as on the general competitiveness of an economy as quantified by the World Economic Forum in its Global Competitiveness Reports.
- Technological capabilities are modelled as the relative patent advantage in wind energy technologies[1]. The national relative patent advantage quantifies the specialisation of a country in technology fields. The data for wind energy technologies was taken from the ISI lead market database (see [21]).
- The competitiveness of complementary sectors was quantified using the revealed comparative advantage (RCA) of the machinery sector[2].

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1 For every country i and every technology field j the Relative Patent Activity (RPA) is calculated according to:

$$RPA_{ij} = 100 * \tanh \ \ln [(p_{ij} / \sum_i p_{ij}) / (\sum_j p_{ij} / \sum_{ij} p_{ij})]$$

2 For every country i, the Revealed Comparative Advantage (RCA) of the technology j takes exports x and imports m into account and is calculated according to:

$$RCA_{ij} = 100 * \tanh \ \ln [(x_{ij}/m_{ij}) / (\sum_j x_{ij} / \sum_j m_{ij})]$$

- Spillovers are modelled as a function of the export shares and the patent advantage.

All these factors were implemented in a system dynamics model, resulting in the model visualised in the Annex. The model was implemented using the software VENSIM.

The exact mathematical relations between the set of variables and the parameters used to have to be calibrated to best reproduce the observed data. The model presented here has been calibrated with data for the technology for generating electricity from wind. For the calibration period (1991-2004), the optimal values for the parameters of the formulae for the calculation of the endogenous variables are searched. This is done by a heuristic approach, during which the endogenous variables are calculated with a large set of different values for the parameters. Partially existing empirical results could be used. The functional relations of the cost advantage, for example, draw on the calculations of a two-factor learning curve for renewable energy technologies developed by Folz [66]. The functional relationships for the feedbacks influencing the RPA draw on the experiences of Grupp/Münt [48] and use a 3-year time lag. In the calibration, different mathematical functions and different time lags for the feedbacks were analysed. These results are compared to the real time series for that variable, and those parameters producing the results best matching the real data are chosen for the model.

Essential to all modelling exercises is the calculation of various scenarios. In these scenarios, the exogenous variables of the model must be specified. In order to test the sensitivity of the model, three scenarios up to the year 2020 were developed which should yield clearly different results:

- Scenario A reflects the reference case: the diffusion of wind energy follows according to the EU-OPTRES scenario “improved policy” [36]. Furthermore, constant R&D spending as in 2004 and a decreasing comparative advantage of German demand factors were assumed, reflecting that other countries will follow the German lead in installing wind power capacity.
- Scenario B reflects an optimistic case in which the lead-market position of Germany is maintained: this scenario assumes a 20% higher diffusion relative to the reference scenario in Germany, reflecting e.g. a higher growth in offshore wind energy. R&D spending is assumed to grow yearly by 2.5%; the other exogenous comparative advantages of national market factors are assumed to be constant.
- Scenario C describes a pessimistic case with reduced support for wind power in Germany: this scenario assumes 50% less diffusion relative to the refer-

ence scenario. R&D is cut down by half until 2020; the decrease in the comparative cost advantage and technological capability of Germany will be stronger than in the reference scenario.

In all scenarios the world trade share of Germany decreases. The stronger diffusion of the technology in other countries increases spillovers and leads to a process of gaining knowledge and building up technological competences in the newcomer countries. The relative advantages of Germany with regard to the cost advantage and the technological capability measured with the RPA are becoming smaller. As the positive feedback loops are not able to compensate for the knowledge spillover which drives the erosion of the lead market, the export share of Germany is declining.

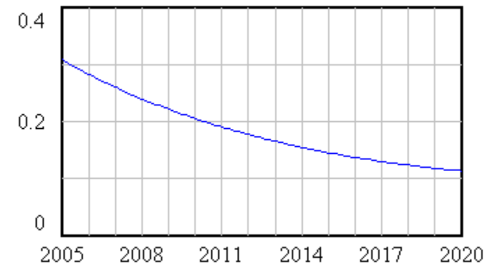
As expected, the results show significant differences between the different scenarios with regard to the size of the German export share:

- 11% in the reference scenario,
- 15% in the optimistic scenario, and
- 9% in the pessimistic scenario.

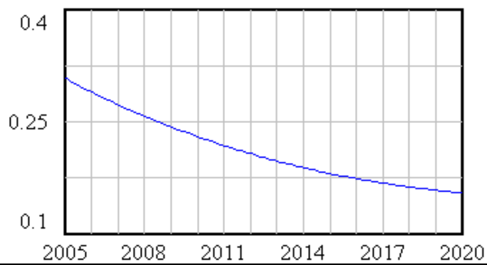
The differences in the results between the scenarios match our expectations and support the postulated hypothesis on what drives the world trade shares. This result is also in the order of magnitude of the expectations of market experts, which forecast a substantial decrease in the German export share of the future [67]. Thus, the model is able to account for the dynamics of export markets driven by the factors which are outlined in theoretical and empirical analyses.

Figure 6: Overview of German world trade shares forecasts for wind energy technologies in the three scenarios

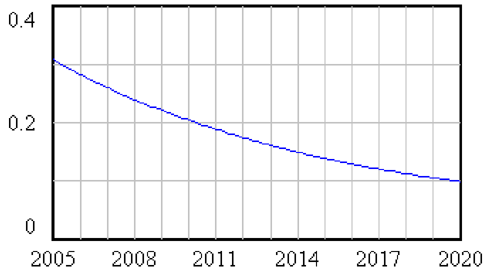
Scenario A: Reference



Scenario B: Optimistic



Scenario C: Pessimistic



In order to further evaluate the robustness of the model and the results, sensitivity analyses were carried out for variations of the demand factors and the soft context factors, the R&D spending and the diffusion of the technology. The parameters were varied according to a normal distribution of values within a given range for each parameter. For each sensitivity analysis, 1,000 model simulations were undertaken for randomly selected values of the analysed parameter. The following patterns emerged with regard to the impacts of these variations on the German world trade shares:

- The variation of both the demand advantage and the soft context factors results in a spread of the world trade shares by 0.4 percentage points. Thus, the effects are rather moderate.
- A stronger impact results for variations of RD spending amounting to about 1 percentage point of world trade shares.
- More important are changes in the diffusion of the technology, resulting in a spread on the world trade shares of 4 percentage points.

The results obtained with the model should not be interpreted as a precise forecast, but rather as showing the underlying basic dynamics which can be expected. Two main aspects need to be considered in interpretation: First, the influence of the knowledge spillovers, which are driving the erosion of existing world market shares, appears to be perhaps too strong. This would work towards an overestimation of the erosion of the lead-market position and towards an underestimation of the markets shares. Second, the time period of the calibration period might have been characterised by a lot of additional noise in the data influencing the calibration of the parameters.

Both problems are interconnected. The spillover variable drives the erosion of a lead-market position. Thus, if during the calibration period the relative lead market factors for a country are highly positive, but the export performance does not follow this, a high importance is attached to the spillover effects. However, there may be the problem that this divergence may be attributed to other (short-term) factors not included in the modelling. Amable and Verspagen [13] point to the importance of capacity restraints which may prevent exports to rise in the short run. During the calibration period of the model, Germany has seen a tremendous increase in installations of wind energy technologies and a strong relative patent advantage (both positive lead market factors), but a low export share only. This can be attributed to the enormous growth in home demand. This growth was so strong that it outpaced the increase in the German capacity to supply wind energy technologies. Not only did German suppliers concentrate on the home market, but the growth in demand was so strong that it even led to a surge in imports, mainly from Denmark. Only at the end of the calibration period, was the capacity shortage removed, resulting in a dramatic shift of German suppliers to the world market. However, in the calibration, this special capacity shortage effect is attributed to the effect of the knowledge spillovers. Thus, the importance the model attaches to the spillovers seems to be too high. In the future, this problem should be reduced if additional years can be included into a new calibration of the model. Another option would be to include capacity shortages as an additional variable in the model.

5 Summary and outlook

In order to model the impacts of a lead market on exports, it is necessary to account for numerous feedback loops between various factors. A pragmatic modelling framework is necessary which accounts for the feedback loops and can be tailored to the data availability. System dynamics can serve as a useful modelling framework. The case of wind energy technology exports from Germany shows that it is possible to implement the factors establishing a lead-market position in such a framework and to establish an empirical model. The empirical results show the expected dynamics of the system and underline the importance of the various feedback loops. A critical methodological reflection suggests the following steps to further improve the model:

- Extending the calibration period will further improve the data fit of the calibrated results. As more data is collected, this might become feasible. This will also allow for using additional time lags beside the already implemented 3 year lag of the influence of the RPA on the WTS.
- The problem of capacity shortages of technology supplies, which limit the availability to establish and exploit a possible lead-market position, has to be addressed, perhaps by including additional variables in the model.
- This first model concentrated on Germany, and treated the competing countries as one aggregate; a more sophisticated model would have to distinguish the other relevant countries separately.
- More feedback loops could be introduced and more of the variables modelled endogenously.
- Developing similar models for other technologies and implementing them would increase the experience gained with the models, and could help to distinguish which results are technology-specific, and which common mechanisms can be applied for a larger set of technologies.

To sum up the experience, the modelling approach is able to provide a consistent approach for modelling the complex interplay of the various factors which drive international trade in the case of lead markets. The following key advantages of the system dynamics approach open up new avenues for modelling international trade: the ability to include the feedbacks between the different variables, the flexibility to utilize complementary empirical approaches and the integration of different databases into a common framework. Growing sophistication of the models will contribute to improve forecasting the impacts of lead market based first mover advantages on exports.

6 References

[1] EU (2007): A lead market initiative for Europe, Communication of the EU Commission EU (COM 2007-860), Brussels.

[2] Beise, M. (2004): Lead markets: country specific drivers of the global diffusion of innovations. Research Policy, Vol. 33, pp. 997-1028.

[3] Blümle, G. (1994): The Importance of Environmental Policy for International Competitiveness, in: Matsugi, T; Oberhauser, A. (eds.): Interactions between Economy and Ecology, Berlin, pp. 35-57.

[4] Porter, M. E.; van der Linde, C. (1995): Toward a new conception of the environment-competitiveness relationship. Journal of Economic Perspectives, 9 (4), pp. 97-118.

[5] Walz, R. (2006): Impacts of Strategies to Increase Renewable Energy in Europe on Competitiveness and Employment. Energy & Environment, Vol. 17 (2006), No. 6, pp. 951-975.

[6] Walz, R.; Schleich, J. (2009). The economics of climate change policies, Springer, Heidelberg.

[7] Verspagen, B. (2009): The use of modelling tools for policy in evolutionary environments. Technological Forecasting & Social Change 76 (2009) 453–461.

[8] Faber, A.; Frenken, K. (2009): Models in evolutionary economics and environmental policy: Towards an evolutionary environmental economics, Technological Forecasting & Social Change 76 (2009) 462–470.

[9] Ekins, P.; Speck, S. (1998): The impacts of environmental policy on competitiveness: theory and evidence, in: Barker, T.; Köhler, J. (eds.): International Competitiveness and Environmental Policy, Edward Elgar, Cheltenham, pp. 33-70.

[10] Meyer-Krahmer, F. (2004): Vorreiter-Märkte und Innovation, in: Steinmeier, F.W.; Machnig, M. (eds.): Made in Deutschland 21', Hamburg, pp. 95-110.

[11] Archibugi, D.; Michie, J. (1998): Technical Change, Growth and Trade: New Departures in Institutional Economics. Journal of Economic Surveys, Vol. 12, No. 3, pp. 313-332.

[12] Archibugi, D.; Pietrobelli, C. (2004): The globalisation of technology and its implications for developing countries – Windows of opportunity or further burden? Technological Forecasting and Social Change, Vol. 70, pp. 861-883.

[13] Amable, B.; Verspagen, B. (1995): The role of technology in market shares dynamics. Applied Economics, Vol. 27, pp. 197-204.

[14] Wakelin, K. (1998a): The role of innovation in bilateral OECD trade performance. Applied Economics, 1998, 30, pp. 1335-1346.

[15] Andersson, M.; Ejermo, O. (2008): TECHNOLOGY SPECIALIZATION AND THE MAGNITUDE AND QUALITY OF EXPORTS. Economics of Innovation and New Technology, Vol. 17, pp. 355-375.

[16] Vernon, R. (1966): International Investment and International Trade in the Product Cycle. Quarterly Review of Economics Vol. 88, pp. 190-207.

[17] Krugman, P. (1979) A model of innovation, technology transfer, and the world distribution of income. Journal of Political Economy, 87, pp. 253–266.

[18] Grossman, G. M.; Helpman, E. (1991a): Quality Ladders and Product Cycles. Quarterly Journal of Economics 106, pp. 557-586.

[19] Grupp, H. (1998): Foundations of Innovation Economics and Indicators, Edward Elgar, Cheltenham.

[20] NISTEP (2005): Science and Technology Foresight Survey: Delphi analysis (NISTEP Report No. 97), Tokyo 2005.

[21] Walz, R. et al. (2008a): Zukunftsmärkte Umwelt - Innovative Umweltpolitik in wichtigen Handlungsfeldern, Reihe Umwelt, Innovation, Beschäftigung of the German Environment Ministry, No. 2008-3, Berlin 2008.

[22] von Hippel, E. (1988): Sources of innovation, New York.

[23] Porter, M. E. (1990): The Competitive Advantage of Nations, New York.

[24] Dosi, G.; Pavitt, K.; Soete, L. (1990): The Economics of Technical Change and International Trade, New York.

[25] Blind, K.; Bührlen, B.; Menrad, K.; Hafner, S.; Walz, R.; Kotz, C. (2004): New Products and Services: Analysis of Regulations Shaping New Markets. Office for Official Publications of the EU, Luxembourg.

[26] Beise, M.; Rennings, K. (2005): Lead markets and regulation: a framework for analyzing the international diffusion of environmental innovations. Ecological Economics, Vol. 52, No.1, pp. 5–17.

[27] Walz, R. (2007): The role of regulation for sustainable infrastructure innovations: the case of wind energy. International Journal of Public Policy, Vol. 2 (2007), No. 1/2, pp. 57-88.

[28] Reiche, D.; Bechberger, M. (2004): Policy differences in the promotion of renewable energies in the EU member states. Energy Policy, Vol. 32, No. 7, pp. 843-849.

[29] Lauber, V.; Mez, L. (2004): Three decades of renewable energy politics in Germany. Energy&Environment, Vol. 15, No. 4, pp. 599-623.

[30] Mitchell, C.; Connor, P. (2004): Renewable energy policy in the UK. Energy Policy Vol. 32, pp. 1935-1947.

[31] Langniss, O.; Wiser, R. (2003): The renewables portfolio standard in Texas: an early assessment. Energy Policy, Vol. 31, pp. 527-535.

[32] Meyer, N. I. (2004): Development of Danish wind power market. Energy & Environment, Vol. 15, No. 4, pp. 657-673.

[33] Foxon, T.J. et al. (2005): UK innovation systems for new and renewable energy systems: drivers, barriers and system failures. Energy Policy, Vol. 33, pp. 2123-2137.

[34] Bird, L. et al. (2005): Policies and market factors driving wind power development in the United States. Energy Policy, Vol. 33, pp. 1397-1407.

[35] Menz, F.C. (2005): Green electricity policies in the United States: case study. Energy Policy Vol. 33, pp. 2398-2410.

[36] Ragwitz, M. et al. (2005): Analysis of the renewable energy sources' evolution up to 2020, Final Report of the FORRES Project to the CEC, Fraunhofer ISI, Karlsruhe, March 2005.

[37] Szarka, J. (2006): Wind power, policy learning, and paradigm change. Energy Policy, Vol. 34, pp. 3041-3048.

[38] Alkemade, F. et al. (2007): Analysing emerging innovation systems: a functions approach to foresight. International Journal Foresight and Innovation Policy, Vol. 3, No.2, pp. 139-168.

[39] Ragwitz, M.; Huber, C.; Resch, G. (2007): Promotion of Renewable Energy Sources: Effects on Innovation, International Journal of Public Policy, Vol. 2 (2007), No. 1/2, pp. 32-56.

[40] Lewis, J; Wiser, R. (2007): Fostering a renewable energy technology industry: An international comparison of wind industry policy support mechanisms. Energy Policy 35, pp. 1844–1857.

[41] Jacobsson, S. Bergek, A.; Finon, D.; Lauber, V. Mitchell, C.; Toke, D.; Verbruggen, A. (2009): EU renewable energy support policy: Faith or facts? Energy Policy 37 (2009) 2143-2146.

[42] Hekkert, M.P. and S.O. Negro, 2009, Functions of innovation systems as a framework to understand sustainable technological change: Empirical evidence for earlier claims. *Technological Forecasting and Social Change*, *Volume 76 (4)pp. 584-594.*

[43] Dosi, G.; Soete, L. (1988): Technical change and international trade, in: Dosi, G. et al. (eds.): Technical Change and Economic Theory, Pinter, London.

[44] Fagerberg, J. (1995a): Technology and Competitiveness. Oxford Review of Economic Policy, Vol. 12, No.3, pp. 39-51.

[45] Fagerberg. J. (1988): International Competitiveness. The Economic Journal, 98 (June): 355-374.

[46] Greenhalgh, C.; Mavrotas, G.; Wilson, R. (1996): Intellectual property, technological advantage and trade performance of UK manufacturing industries. Applied Economics 28, No. 5, pp. 509-519.

[47] Wakelin, K. (1997): Trade and Innovation, Cheltenham.

[48] Grupp, H.; Münt, G. (1998): Trade on High-Technology Markets and Patent Statistics – Leading-Edge versus High-Level Technology. In: Archibugi, D.; Michie, J. (eds.): Trade, Growth and Technical Change. Cambridge (UK): Cambridge University Press, 1998, pp. 168-187.

[49] Blind, K. (2001): The impacts of innovations and standards on trade of measurement and testing products: empirical results of Switzerland's bilateral trade flows with Germany, France and the UK. Information Economics and Policy 13 (2001) 439-460.

[50] Sanyal, P. (2004): The role of innovation and opportunity in bilateral OECD trade performance. Review of World Economics Vol. 140, No.4, pp. 634-664.

[51] Lachenmaier, S.; Wößmann, L. (2006): Does innovation cause exports? Evidence from exogenous innovation impulses and obstacles using German micro data. Oxford Economic Papers 58 (2006), 317-350.

[52] Madsen, J. B. (2008): Innovations and manufacturing export performance in the OECD countries. Oxford Economic Papers 60 (2008), 143-167.

[53] Fagerberg, J. (1995b): User-producer interaction, learning, and competitive advantage. Cambridge Journal of Economics, Vol. 19, pp. 243-256.

[54] Grossmann, G. M.; Helpman, E. (1991): Trade, knowledge spillovers, and growth. European Economic Review 35, (1991) pp. 517-526.

[55] Griliches, Z. (1991): The Search for R&D Spillovers. Working Paper No. 3768, National Bureau of Economic Research, Cambridge, Mass.

[56] Pain, N.; Wakelin, K. (2004): Export Performance and the Role of Foreign Direct Investment. The Manchester School, Vol. 66, Issue S, pp. 62-88.

[57] Greenaway, D.; Sousa, N.; Wakelin, K. (2004): Do domestic firms learn to export from multinationals? European Journal of Political Economy, Vol. 20, pp. 1027-1043.

[58] Wagner, J. (2007): Exports and Productivity: A survey of the Evidence from Firm-Level Data. The World Economy 30, pp. 817-838.

[59] Wei Yingqi, Y.; Xiaming Liu, X.; Wang, C. (2008): Mutual productivity spillovers between foreign and local firms in China. Cambridge Journal of Economics 2008, 32, 609-631.

[60] Coe, D.; Helpman, E. (1995): International R&D Spillovers. European Economic Review 39(5), pp. 859-87.

[61] Eaton, J.; Kortum, S. (1996): Trade in Ideas, Patenting, and Productivity in the OECD. Journal of International Economics 40(3-4), pp. 51-78.

[62] Keller, W. (1998): Are international R&D spillovers trade related? Analyzing Spillovers among Randomly Matched Trade Partners. European Economic Review 42, pp. 1469-1481.

[63] Branstetter, L.G. (2001): Are knowledge spillovers international or intranational in scope? Microeconometric evidence from the U.S. and Japan. Journal of International Economics 53 (2001) 53-79.

[64] Navaretti, G. B.; Tarr, D. G. (2002): International Knowledge Flows and Economic Performance: A Review of the Evidence. The World Bank Economic Review 14, No.1, pp. 1-15.

[65] Saggi, K. (2002): Trade, Foreign Direct Investment and International Technology Transfer: A Survey. The World Bank Research Observer 17 (2), pp. 191-235.

[66] Folz, A. (2008): Modelling and dynamic simulation of the effects of technological learning on the development of renewable energies in the electricity sector in the EU up to 2050, Master thesis, Fraunhofer ISI, Karlsruhe/Kassel, January 2008.

[66a] Maurseth, P. B.; Verspagen, B. (2002): Knowledge Spillovers in Europe: A Patent Citation Analysis. Scandinavian Journal of Economics 104 (4), pp. 531-545.

[67] ZSW et al. (2006): Auswirkungen des Ausbaus erneuerbarer Energien auf den Arbeitsmarkt, Stuttgart 2006.

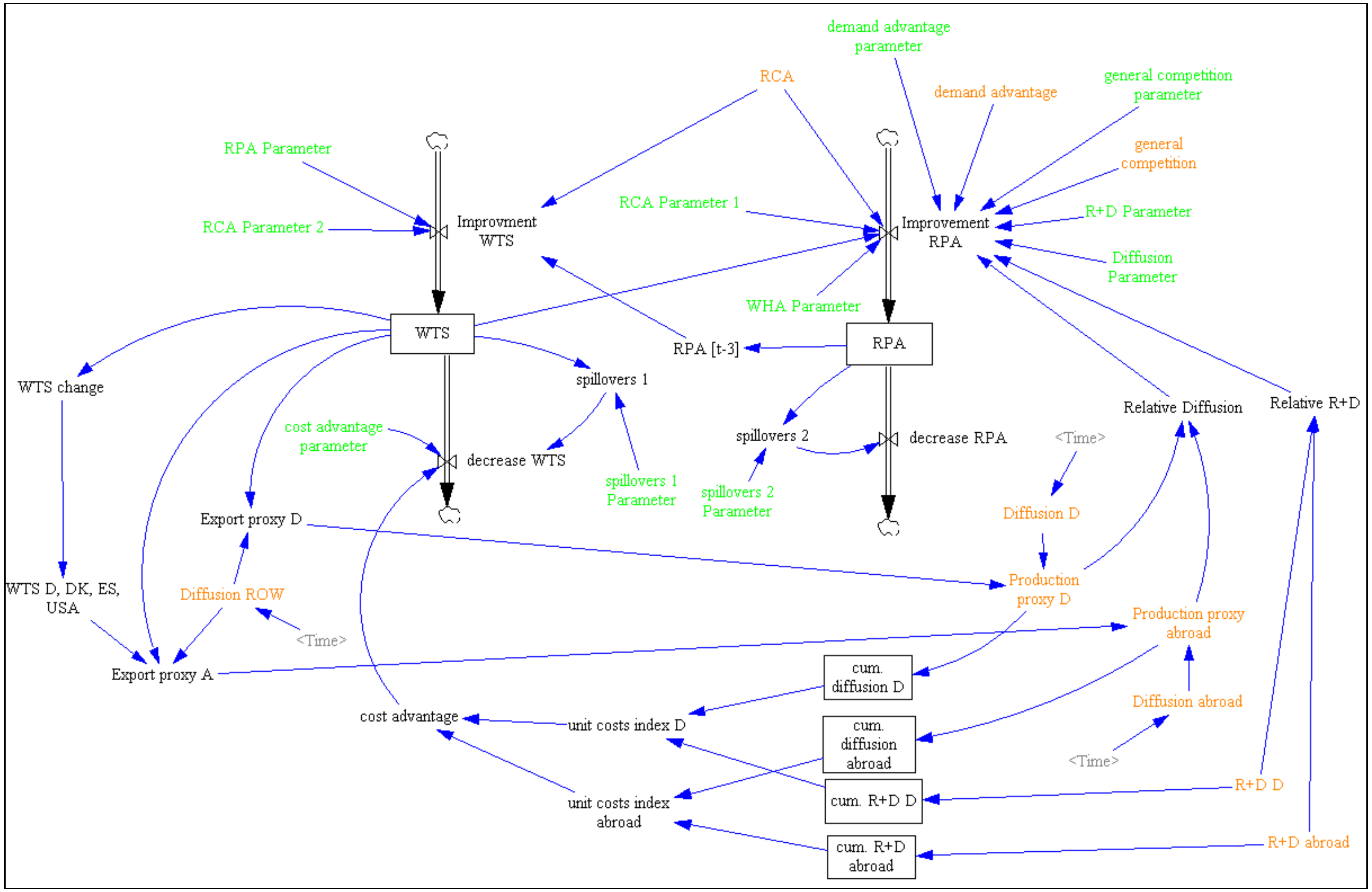
[68] Linder, S. B. (1961): An Essay on Trade and Transformation, Uppsala 1961.

[69] Walz, R. et al. (2008b): Innovation and regulation: the case of renewable energy technologies, DIME working paper series “Environmental Innovation” No. 2, May 2008.

[70] Bergek, A.; Jacobsson, S.; Sandén, B. (2008): 'Legitimation' and 'development of positive external economies': Two key processes in the formation phase of technological innovation systems. Technology Analysis and Strategic Management, 20 (5) pp. 575-592

7 Annex

Lead-market model implemented in VENSIM



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