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Modelling Energy Futures: A CGE framework for investigating investment in renewable energy applied to the EU electricity sector[1]

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Abstract

The paper addresses the issue of introducing renewable electricity production into a CGE framework. This involves introducing an investment function that considers the relationship between two industries that produce the same commodity. This includes the possibility that a small sector (renewable electricity production) may grow more rapidly than would occur under standard model assumptions.

Alternative functional forms for the investment functions are proposed. To analyse these functions, the paper uses the PEP-1-t model, with Europe-27 represented as a single region and the rest of the world exogenous. Each function is introduced into the model code, and tested through a simple simulation (subsidising the purchase of capital equipment).

Comparing the functional forms, the paper suggests how improvements can be made to the standard model in cases where there is the potential for a transition between technologies (such as from conventionals to renewables in electricity production). The paper contends that the split in investment between two such industries should be dependent on the relative rental rates. Furthermore, it is argued that this relationship is best represented by a sigmoid curve, such as the logistic.

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1. Introduction

Many countries are seeking to reduce their reliance on fossil fuels and increase their use of renewable energy. If this is to be accomplished, a rapid shift towards investment in renewable energy will be required.

Within the EU, Directive 2009/28/EC promotes the use of energy from renewable resources, setting a target for 20 percent of gross final consumption of energy to be from renewable sources by 2020. Within this overall energy target, the specific target for electricity is for "over 30 percent" of electricity to be generated from renewable sources, which in 2006 stood at 16 percent. Of this 16 percent, the majority is from hydro-power (9 percent of the total), which is not forecast to increase substantially. Therefore, the other forms of renewable energy (especially wind, solar and biomass), which account for the remaining 7 percent of the total, must triple their share to 21 percent.

This shift of production will require a much greater shift in the pattern of new investment. Shifts of this magnitude present CGE modellers with a challenge. In a traditional modelling framework, the standard equations limit sectoral growth because future investment is largely driven by the existing capital stock. If the changes are to be endogenous (price-driven), large shifts in profitability would be required to induce the investment required for a sector to double in size, let alone grow many times over.

More generally, this is a case where the two activities (renewables and conventionals) are producing the same commodity (electricity), and hence, they are related. The standard investment function gives no particular consideration to related activities that are largely substitutable. In this paper, we propose a number of investment functions for addressing both these points in an attempt to improve on the standard model behaviour.

This paper is structured as follows. The next section gives the modelling methodology. It is in this section where we introduce each of our alternative investment functions. Sections 3 and

4 briefly explain the data used and the simulations that were introduced into the model to test the investment functions. Section 5 gives the results, which allows a comparison between the functions, and section 6 concludes and offers proposals for future development of the research.

2. Modelling Methodology

For this paper, we limit our focus to the electricity sector. The production of electricity is split into different two technological categories: conventional and renewable. Renewable production is a fairly small share of total production; however this is expected to increase rapidly over the next few decades, especially among EU member states. Serious commitments to move towards renewables have been made at both the national and EU level, supported by tax and subsidy incentives. Moreover, with the future of nuclear production in doubt in a number of member states, it becomes yet more difficult for member states to reduce their greenhouse gas emissions. This will increase the pressure to raise the production of renewables.

Bottom-up energy models have no difficulty in demonstrating a rapid growth in renewables (given appropriate assumptions about taxes, subsidies, regulations and technology). However, the standard functional forms of CGE models make it difficult for any small sector to grow quickly. This limits the extent to which growth in renewable production can feature in a standard CGE even when similar changes in subsidies (and so on) are introduced.

In addition to the difficulty in growing a small sector, there is the broader question about how to appropriately model the investment relationship between two related sectors. This is considered in the context of the alternative functional forms posited below.

The paper starts from the PEP-1-t model (PEP-1-t; Decaluwé et al., 2010), which is a single region, recursive dynamic model. The following paragraphs explain the changes made to the code. The key development is to introduce different functional forms for the investment function.

The standard investment function in PEP-1-T is taken from Jung and Thorbecke (2001) and reads as follows:

$$IND_{k,bus,t} = \phi_{k,bus}\left[\frac{R_{k,bus,t}}{U_{k,bus,t}}\right]^{\sigma^{INV}_{k,bus}} KD_{k,bus,t}$$

Where: IND is the new investment; KD is the existing capital stock; R is the rental rate on capital; U is the user cost of capital; sigma_INV is an elasticity; phi is a scale parameter; k is the type of capital; bus is all private sectors; t is the time period.

This functional form has many worthwhile properties making it appropriate in many situations. However, in the particular case investigated in this paper, the implied behaviour is not especially convincing, as will be shown below.

To calibrate investment demand (IND) we have to make an assumption on the capital stock. Thus, from the base year, investment demand and capital demand are proportional. Then, we assume capital is fixed at the base year and then grows according to the new investment realised in the sector between the periods. New capital will be allocated according to the difference in the rate of return in every activity, meaning new capital will go where the rate of return is greater. However, due to the initial constraint, if the initial value of capital is small in a given sector, it will be very difficult to increase substantially the stock of capital in this sector.

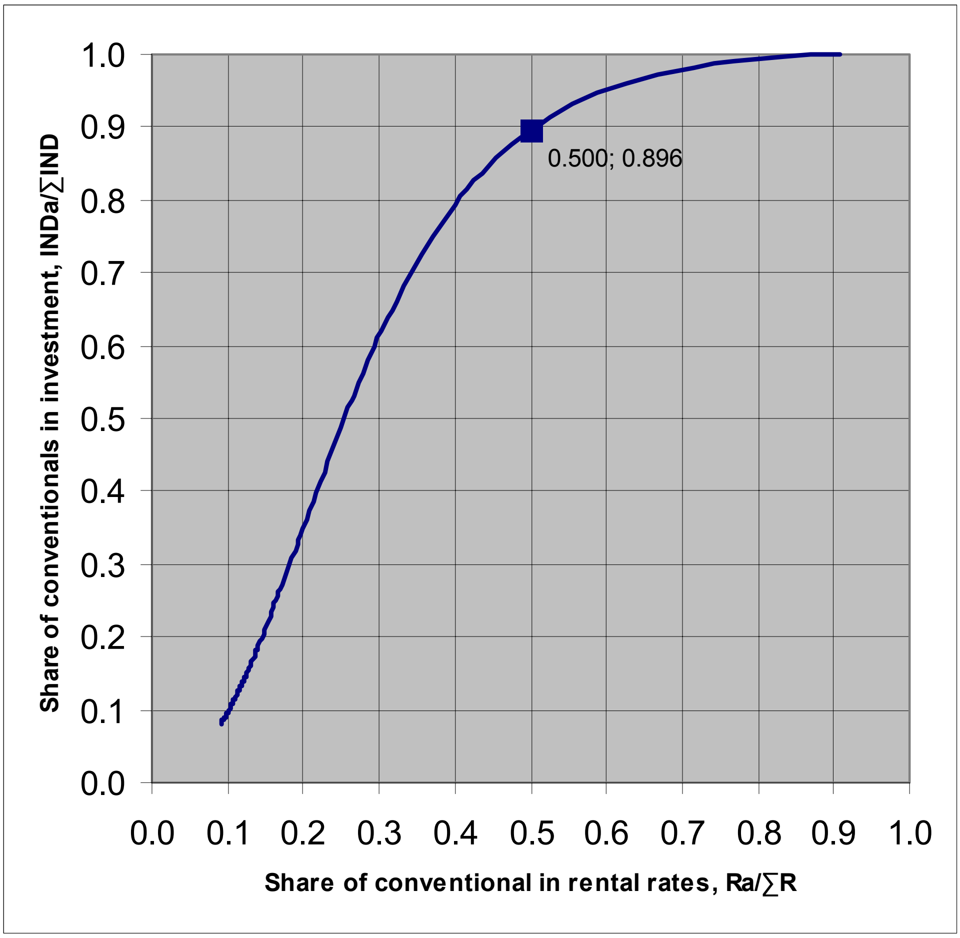
As we would like to take into account the possibility of a transition between technologies (from conventionals to renewables), we propose four methods to adjust this function, the details of which are explained below. To code these changes, firstly, total electricity investment is calculated as in the standard equation above (i.e. investment in renewables plus investment in conventionals, the right-hand side of the above equation, equals the sum of the left-hand side of the equation for renewables plus that for conventionals).

Secondly, within this total electricity investment, the share of electricity capital investment going to conventionals (labelled SHKI) is calculated. The key contribution of this paper is a comparison of alternatives for calculating how this split should occur. The following sub-sections explain how SHKI, and hence the split between renewable and conventional investment is calculated, beginning with the standard function for comparison.

2.1. Standard Investment Function (INVFN=1)

In order to understand the different options for the split between renewables and conventionals, it is important to firstly analyse how the standard investment function operates with respect to the relative rental rates. Figure 1 shows a comparison of the relative rental rates graphed against the share of electricity investment in conventionals.

Figure 1: Standard investment function (INVFN=1)



The default parameterisation of the PEP-1-t model is that the rental rates are equal. Therefore, the share of conventional rental rates, compared with total electricity rental rates (i.e. $R_{conventional}$ / ($R_{conventional}$ + $R_{renewable}$)) is equal to 0.5. With the original data (see section 3 for details), the share of conventionals in total electricity investment is 89.6 percent. Therefore the point (0.500,0.896) is highlighted in Figure 1. Moving to the left on the x-axis implies that conventionals have a progressively lower rental rate relative to renewables. It can be seen that as the rental rate of conventionals falls, the investment share also falls. For example, when the share of the total rental rate is 33.3 percent (i.e. the rental rate on renewables is twice that of conventionals), the investment share falls to 68 percent conventionals (and 32 percent renewables). Moving to the right on the x-axis implies that conventionals have a progressively higher rental rate relative to renewables, and hence take an even larger share of the total investment in electricity.[2]

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[2] Note that for the purposes of this analysis, the capital stock levels were left unchanged.

2.2. Investment function 2 (INVFN=2) – Multiple by a Power of Rental Share

This investment function takes the standard function but increases the importance of the relative rental rate. The equation is shown below.

$$SHKI_{k,conv,t} = \left\{ \frac{\left(R_{k,conv,t} \Big/ \sum_{ele} R_{k,ele,t} \right)}{\left(RO_{k,conv,t} \Big/ \sum_{ele} RO_{k,ele,t} \right)} \right\}^{sigma\_SHKI_{k,conv,t}} SHKISTND_{k,conv,t}$$

Where: ele is the set of all energy production (conventionals and renewables); RO is the initial level of the rental rate, R; sigma_SHKI is an elasticity that determines the sensitivity of investment levels to changing relative rental rates

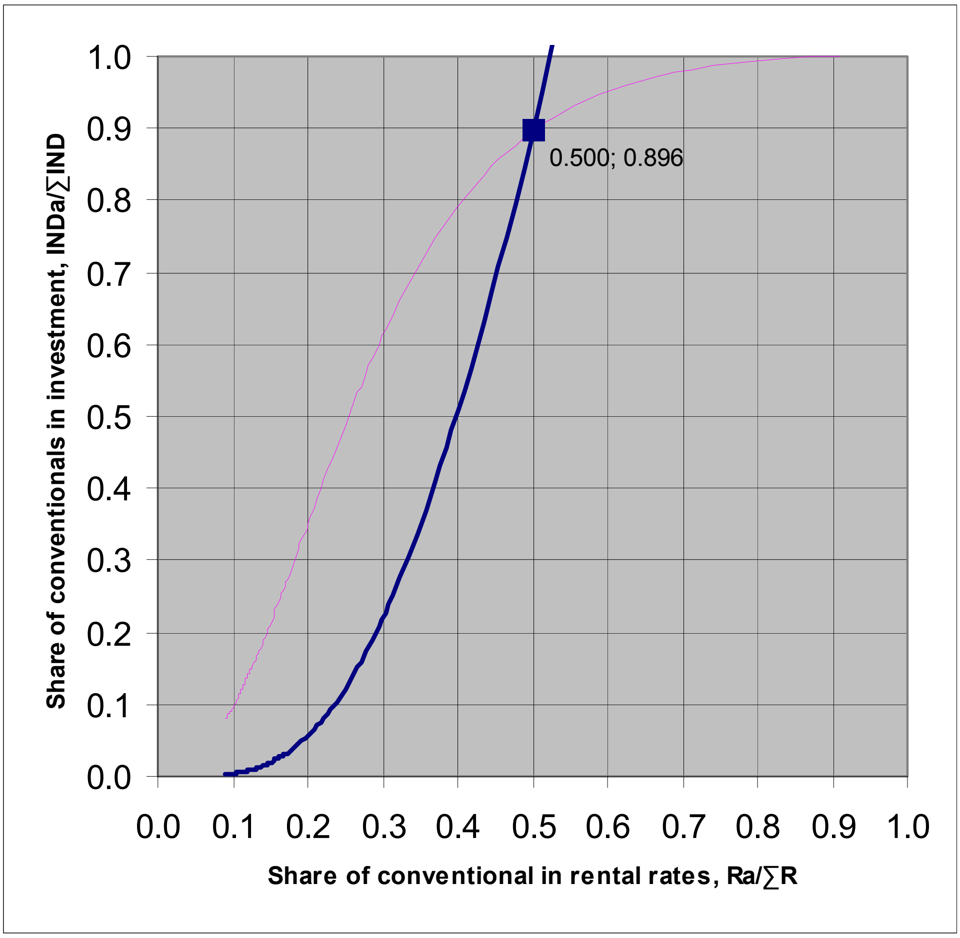
The standard function (represented by SHKISTND) is augmented by multiplying it by the rental rate of conventionals as a share of the combined rental rates, relative to the initial relative rental rates.

Important in this specification is how responsive the function is, as determined by the elasticity, sigma_SHKI. A sigma_SHKI of zero would mean no responsiveness (and hence, a replication of the standard model). Increasing the size sigma_SHKI, increases the responsiveness. However, note that for high values, the function can become unstable,[3] which is not a realistic outcome. Partly for this reason, a value of 2 for sigma_SHKI was used in the following simulations.

Note that this option still features investment levels that related to the original level of capital stock (though there is a greater propensity for the shares to shift). This can be seen from Figure 2 below.

[3] Meaning that instead of steady growth, the share of investment oscillates, rising in one period, falling in the next, with the magnitude of each growing over time. Care must be taken to check for this behaviour.

Figure 2: Investment function with power of rental share added (INVFN=2)



The thin pink line is the standard function for comparison. It can be seen that as conventionals become relatively less profitable (i.e. the rental rate falls compared with that for renewables) that the share of conventionals drops much faster than in the standard model. However, one also notes that if the relative rental rate for conventionals increases, the share quickly becomes nonsensical with shares in excess of 100 percent. For this reason, this functional form only works if the relative rental rate on conventionals is steady or falling.

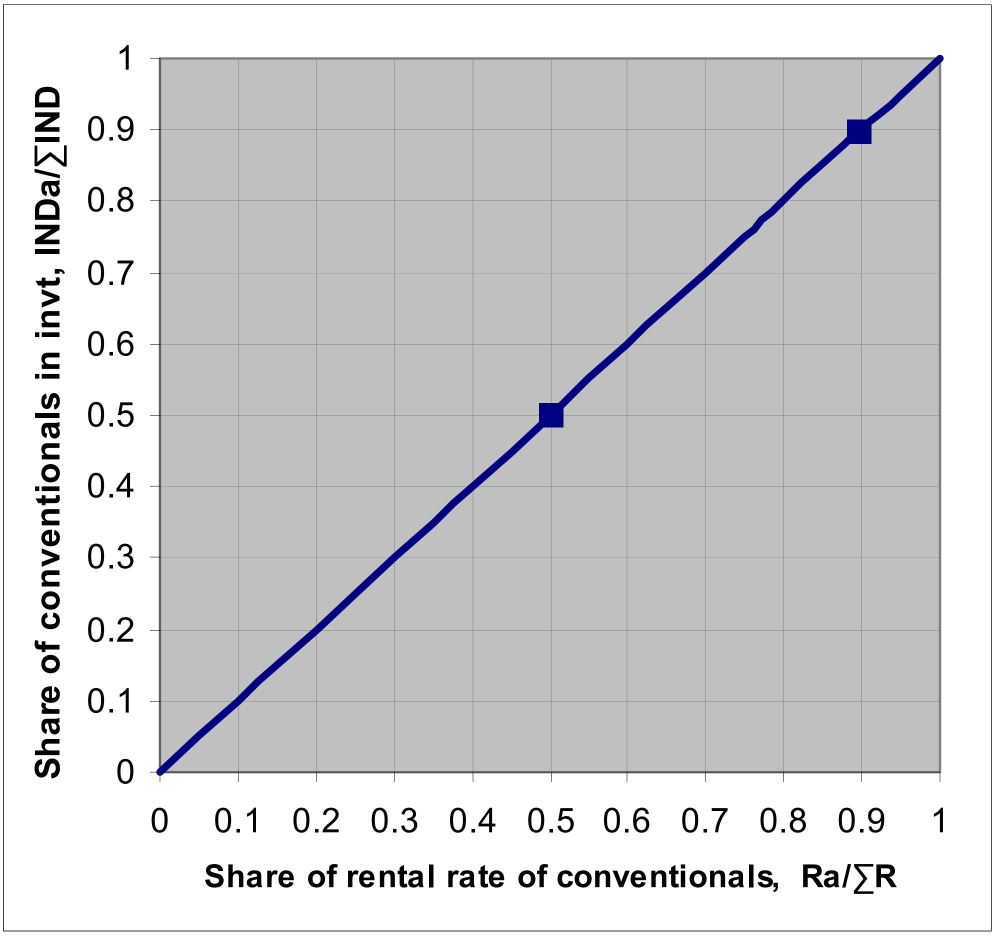
2.3. Investment function 3 (INVFN=3) – 1-to-1 Relationship

This investment function disassociates the split between conventionals and renewables from the level of capital stock, making it dependent only on the relative rental rates. The relationship between the relative rental rates and the relative investment shares is the simplest possible: a straight line.

$$SHKI_{k,conv,t} = \left(R_{k,conv,t} \Big/ \sum_{ele} R_{k,ele,t} \right)$$

If both conventionals and renewables are equally profitable, then the investment in electricity production will be split between them. If one is more profitable, it will receive a higher share of the investment in electricity than the other.

Figure 3: Investment function with 1-to1 relationship between the rental rate and investment shares



There are two options for the initial parameterisation of this function. If one keeps to the default balancing of rental rates, then the initial point is (0.5,0.5), which implies an equal split in investment between renewables and conventionals (INVFN=3a). Note though that this implies a 'shock' to the model, as the initial investment level from the data is 89.6 percent conventionals. This would imply a structural break – the future is different from the past. This would have to be justified by some kind of major policy or technology shift.

The alternative is to parameterise at the initial investment level (INVFN=3b). This gives the point (0.896,0.896).

Note that this function has a shallow slope, and therefore, requires large shifts in the rental rate to cause significant changes in the share of conventionals.

2.4. Investment function 4 (INVFN=4) – Power Relationship

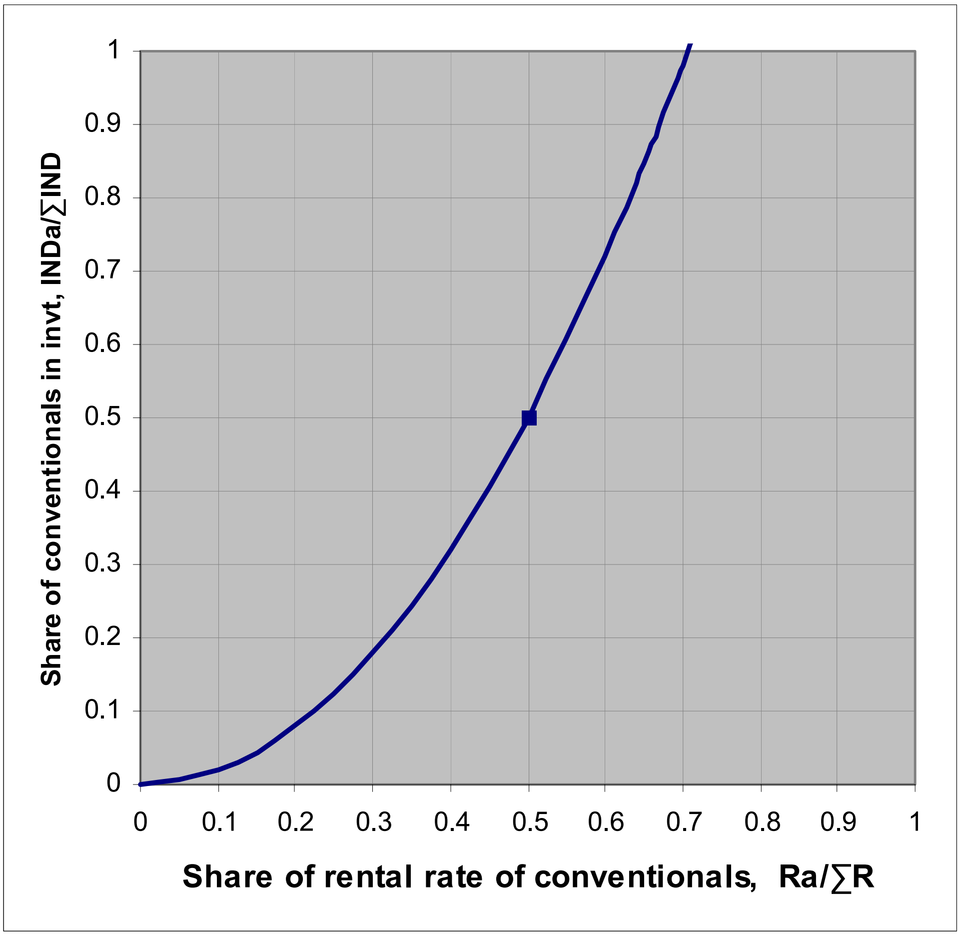
The fourth option (INVFN=4) develops the third function by adding a sensitivity to changes in relative rental rate. This is similar to how the standard function was augmented in INVFN=2. The equation for SHKI is as follows.

$$SHKI_{k,conv,t} = \left(RO_{k,conv,t} \Big/ \sum_{ele} RO_{k,ele,t} \right) \left\{ \frac{\left(R_{k,conv,t} \Big/ \sum_{ele} R_{k,ele,t} \right)}{\left(RO_{k,conv,t} \Big/ \sum_{ele} RO_{k,ele,t} \right)} \right\}^{sigma\_SHKI_{k,conv,t}}$$

As for INVFN=2, the value of sigma_SHKI is important with a higher value implying more responsiveness of investment to the changes in the relative rental rates. For this analysis, the value of simga_SHKI was set at 2.

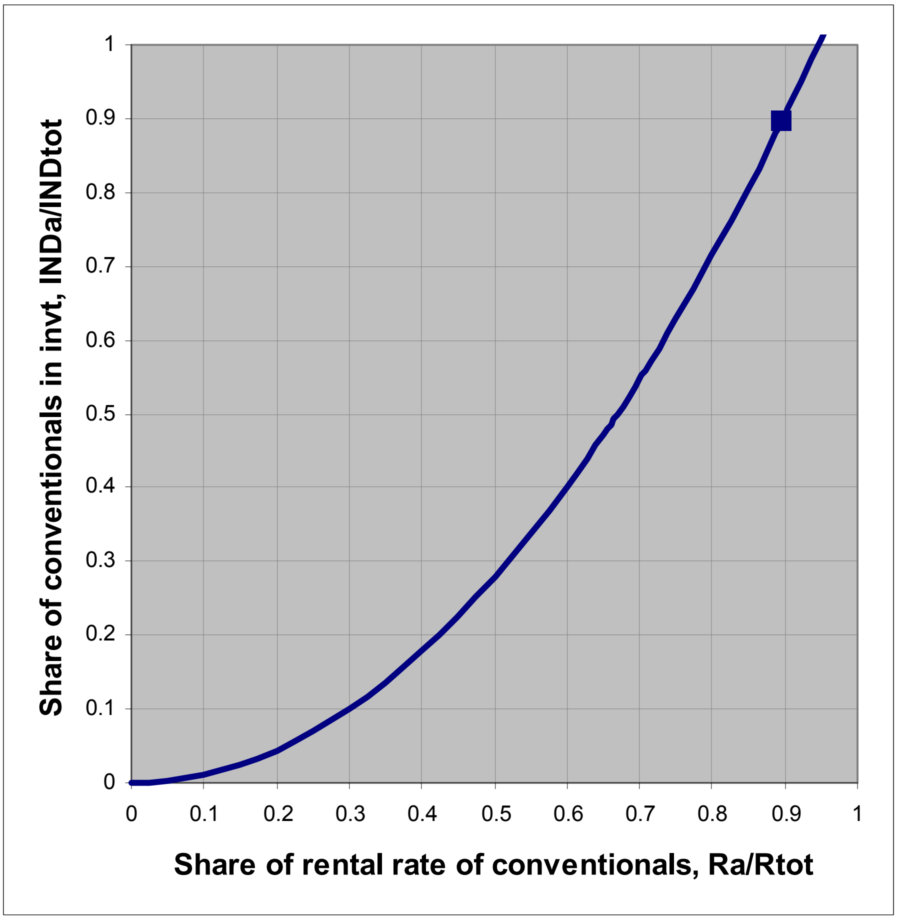
As for INVFN=3, this could be parameterised at equal rental rates (INVFN=4a), which gives the relationship between relative rental rates and investment shares as shown below in Figure 4. Note that as for INVFN=3a, this implies a structural break with the past. Furthermore, notice that if the share of conventional rental rate out of the total rental rate rises the investment response is not intuitive, and were it to exceed 0.707, then the share in investment would exceed 100 percent. Nevertheless, provided that conventionals are becoming relatively less profitable, the response appears reasonable.

Figure 4: Investment function with power relationship between the rental rate and investment shares – parameterised at equal rental rates



Were the function to be parameterised to the initial investment level (INVFN=4b), the relationship would be as in Figure 5 below. This allows some responsiveness to relatively increasing profitably of renewables, though similar caveats to those mentioned for INVFN=4a still apply.

Figure 5: Investment function with power relationship between the rental rate and investment shares – parameterised at initial investment level



2.5. Investment function 5 (INVFN=5) – Logistic Relationship

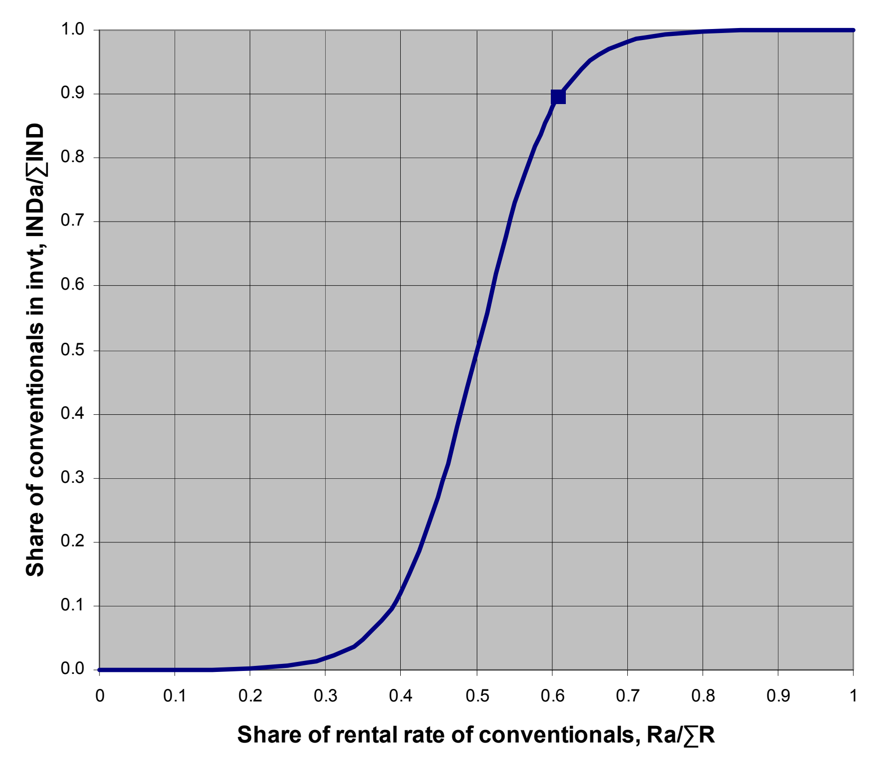
This investment function suggests an alternative relationship between the rental rate shares and the investment shares. The equation is as follows.

$$SHKI_{k,conv,t} = \frac{1}{1 + e^{-\beta\left[2\left(R_{k,conv,t} \Big/ \sum_{ele} R_{k,ele,t}\right) - 1\right]}}$$

Where β determines the steepness of the slope.

The arguments of the logistic are representative of the different rates of return in the conventional/renewable sectors. One has to be careful on the values given to the different arguments on the logistic as the output can be sensitive to the choices. For this analysis, the argument β was given a value of 10, which traces out a logistic relationship as shown below in Figure 6.

Figure 6: Investment function with logistic relationship between the rental rate and investment shares



This function can be parameterised to the initial investment level, which is highlighted (0.608,0.896). This implies that the initial rental rate for conventionals is slightly more than 50 percent higher than that for renewables (0.608 compared with 0.392 for renewables).

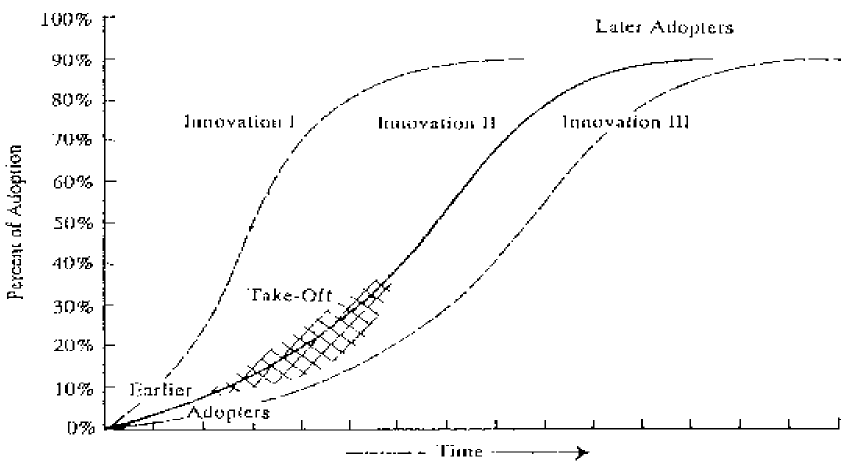
This functional form has a number of desirable properties, which are worth describing. Some of these are shared by the other alternatives considered above, but only sigmoid functions, such as the logistic, satisfy all of them. Notable properties include the following:

a. The split between renewables and conventionals is dependent only on rental rates (not the level of capital stock).
b. If there are equal rental rates, then there are equal investment shares. If one has higher rental rate, then gets higher share. Note also that this occurs symmetrically with the logistic function.
c. The function represents increasing returns to scale at low levels of investment, until an inflexion point, and then decreasing returns to scale at high levels.
d. There is the possibility of a rapid response to changing rental rates, if this is desired. (The fact that this is flexible, being dependent on the slope parameters chosen, is also desirable.)
e. The function has been parameterised to initial investment levels (89.6 percent conventionals). Though the possibility of introducing a structural change was posited for INVFN=3a and 4a, on balance, it is easier to justify this type of parameterisation.

The conceptual argument for introducing this type of function is strengthened by considering the process of transition between technologies. At low levels of investment, many technologies have what could be described as 'teething problems'. Certainly, costs may remain somewhat too high, but also the regulatory framework may be underdeveloped (e.g. the establishment of the rights to build wind farms), the availability may be limited or decision-makers may consider them too risky.

Of relevance here is the literature about diffusion of innovations. The process is summarised in Figure 7.

Figure 7: Typical Diffusion of Innovation Pattern



Source: Rogers, 2003:11

Successful innovations begin with a small number of early adopters. At some point, there is a take-off, with rapid adoption rates. Once the majority of the potential market possesses the product, the adoption rate slows down. This produces a sigmoid curve as shown.

Though the transition process between alternative technologies is not precisely analogous to that for new technologies, there is an intuitive sense in which the transition to renewable energy could follow a similar path. In recent decades, investment in renewables has been a small, but growing, part of the energy mix in Europe. It is typically still the case that they are somewhat more expensive than conventionals. However, with sufficient government incentives (as well as a generally more favourable policy environment), the possibility for 'take-off' of renewable technology is plausible. Indeed, in some countries it has begun, and many others plan to follow. Considering that few empirical studies have been carried out, a sigmoid function for this relationship is the most plausible initial assumption.

3. *Data*

The model uses the GTAP7 database, aggregating the values for the EU-27 to the single region. The 57 GTAP industry sectors were aggregated into seven sectors (agriculture, fossil fuels, electricity, manufacturing, transport, other private services, public services). As GTAP has an aggregated electricity sector, it was necessary to split the production of electricity into two sectors. This was done using values from the International Energy Agency for the EU 2008.[4] For this split, renewables was defined to include biomass, waste, wind, tide, geothermal and solar.[5] This gave the share of renewables in the production of electricity as 7.27 percent of the total.

The inputs to electricity in the input-output table values were split between conventional and renewable electricity production with the exception of fossil fuels, which are only used in conventional production, and agriculture, which is only used in renewable production (biomass). On the consumption side, the single electricity sector is used.

4. *Simulations*

The simulations make use of each of the investment functions outlined above. The key investigation is how important the functional form is with respect to a gradual shift in the relative rental rates. This was done through a gradually rising subsidy on renewable capital. The subsidy is ad valorem, with no subsidy in the base year (actually, there is a small tax in the base year). Then a five percent subsidy to the price of renewable capital introduced in the second time period, rising by five percent per year, until in the 10th and final period the subsidy in 45 percent. Note that the choice of a subsidy on capital is *illustrative*.[6]

The subsidy clearly makes renewables more attractive compared with the base case. The interest is the extent to which the functional form changes the responsiveness of investment decisions to this incentive.

This produces six simulations: the business-as-usual (BAU) runs versus the subsidies on renewable capital (SUBS) for each of the investment functions.

5. *Results*

Before focusing on the electricity sector, we firstly consider the mechanisms of the set up of a subsidy for a given sector. We can point out 2 different effects. The first one will apply only on the specific sector that benefits from the subsidy: its production should increase

[4] Data downloaded March 2011 from IEA web site: http://www.iea.org/stats/index.asp.
[5] Hydroelectric power was excluded as (i) the figures are inclusive of pumped storage planted, which inflate the figures and (ii) little of the increase in renewables is projected to come from hydroelectric power.
[6] Other options tried include introducing a subsidy on final production or increases in total factor productivity.

and, year after year, investment should increase in this sector. This can have as well an impact on the other sectors, as the given sector needs inputs from the other sectors to increase its production. The second effect occurs because there is no fiscal policy to finance the subsidy policy. This will lead to a drop in government savings and thus in total investment that also slightly reduces overall GDP growth.

Thus we know that whatever the scenario, we will have a drop in total investment and GDP at the end of the period.

Table 1: Impact on total investment and GDP in the long run (in % to the BAU values)

Investment function (with gradually rising subsidy, unless stated)	Total Investment	GDP
1. Standard	-0.636%	-0.005%
2. Stnd + power	-0.990%	-0.003%
3a. 1-to1 equal R	-1.238%	-0.016%
3b. 1-to-1 initial invt level	-0.494%	-0.014%
4a. As 3a + power	-1.299%	-0.018%
4b. As 3b + power	-0.576%	-0.022%
5. Logistic	-0.867%	-0.019%

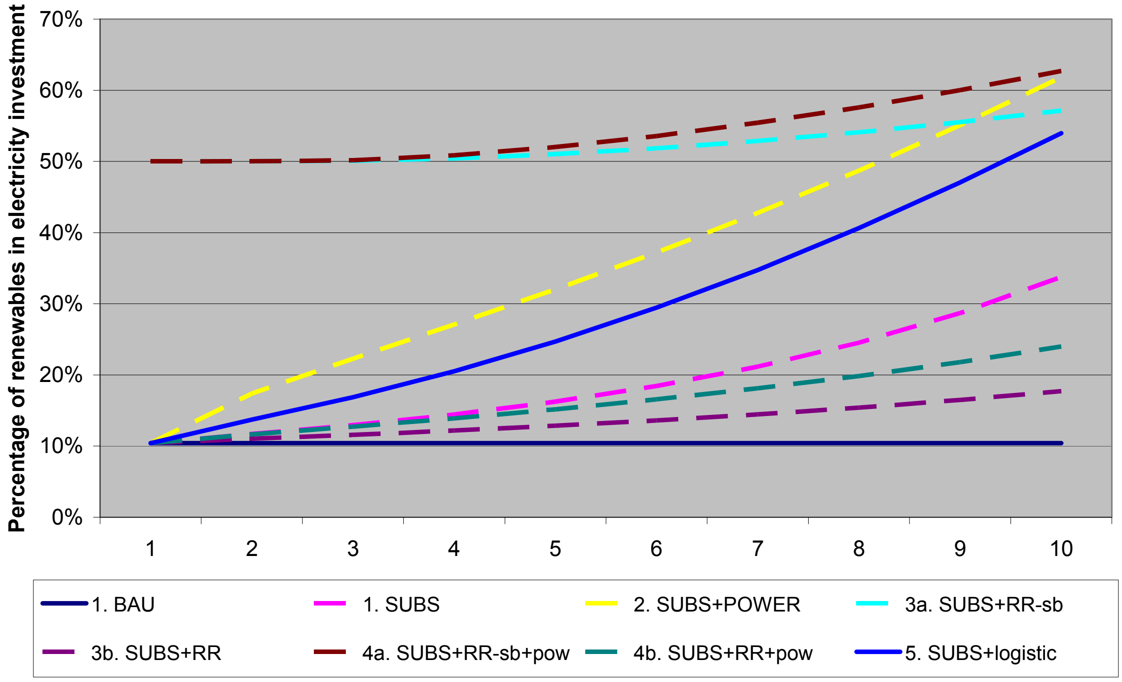
From table 1 above, we can see that the impacts on total investment and GDP are quite similar whatever the scenario.

Turning to the renewable electricity sector, we can see from figure 8 below that investment levels in this sector is particularly high for the case 2, where the share of renewable is rapidly increasing, starting at its BAU value. We observe the same pattern for the logistic case.
Indeed, the lowest line represents the BAU scenario with no subsidies. As can be seen, introducing subsidies increases the investment level significantly. Indeed, using renewable capital to produce energy is relatively cheaper, and as we allow substitution between conventional and renewable, then the demand for renewable is going to increase.
However, for dramatic increases to take place, it is necessary to add the additional responsiveness to the relative rental rate from investment function 2 (INVFN=2).

Investment function three (INVFN=3), which ignores previous investment levels, starts from a high level of investment. Though it does grow from this position, the growth is not especially rapid.

We are actually particularly interested in the difference between the pink curve (subsidies with a standard model), and the other curves, especially the blue one (logistic) and the yellow one (power). From this graph, we can see the difference (and the use) in using different specification for investment demand in this particular sector. At the end of the period, for a standard specification, the share of renewable in energy investment is a little more than 30%, whereas using whether a logistic or a power is greater than 50%.

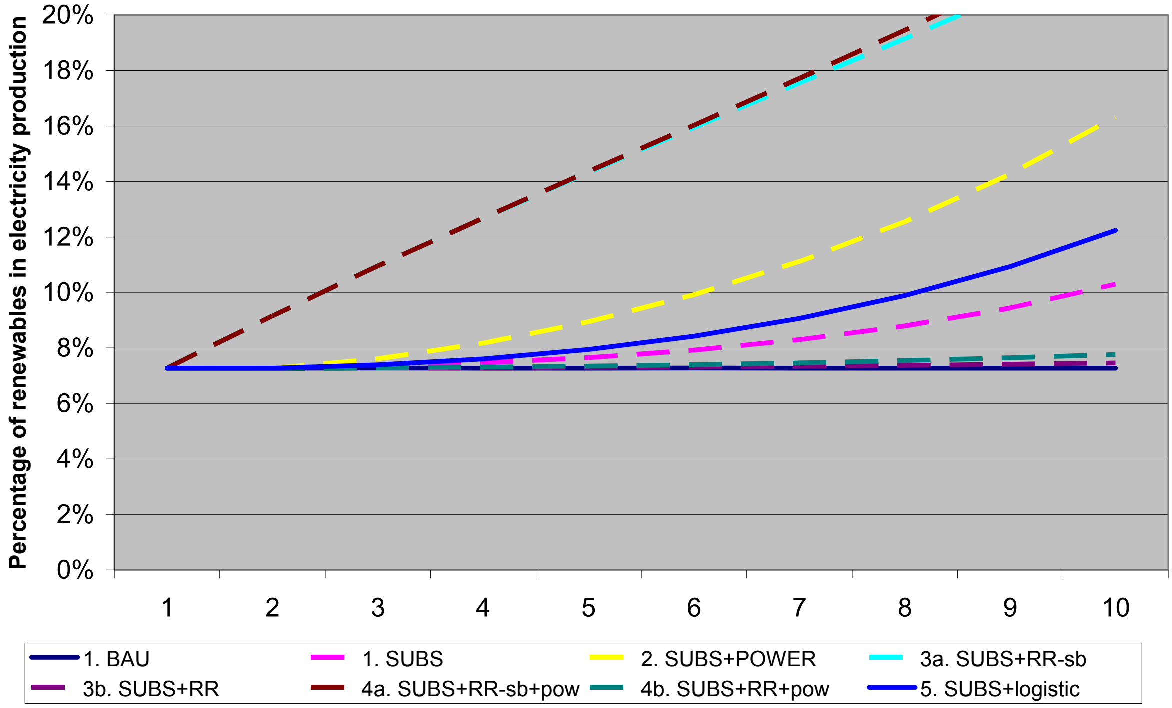
Figure 8: Comparing the Investment Levels in Renewables from Different Investment Functions



In terms of the amount of production from renewables, we observe the same pattern. In the BAU scenario, we hardly have little change (simply growing by the population growth rate). Adding the subsidy, to the base model (SUBS; INVFN=1) does spur more production, though the stronger results from the second investment function (INVFN=2) are clear. Though we saw above that in the final period, this second function does spur slightly more investment than the third function, the cumulative effect of starting the change in investment patterns early is substantial, as can be seen clearly below (INVFN=3).

Here again, it is interesting to compare the pink curve to the blue and yellow ones. Using these specifications allows a substantial increase in the share of renewable in electricity production. However, and this is very interesting, using specifications that rely only on the rental rates (in the 1 to 1 relationship) has non willing results, but we already knew that this specification needed large shifts in the rental rate to cause significant changes in the share of conventionals.

Figure 9: Comparing the Production Levels of Renewables from Different Investment Functions



Looking at the composition of electricity production at the end of the period, we can see from table 2 that 2 scenarios give results below the standard specification, for the reasons explained above. For the other scenarios, we have a significant increase in the share of renewable in electricity production.

Table 2: Impact on the shares of renewables in electricity investment and electricity production in the long run

Scenarios	Percentage renewables out of total electricity investment in period 10	Percentage renewables out of total electricity production in period 10
Base (no subsidies)	10.4%	7.3%
1. Standard	33.8%	10.3%
2. Stnd + power	61.8%	16.3%
3a. 1-to1 structural break	57.1%	22.4%
3b. 1-to-1 initial invt level	17.7%	7.5%
4a. As 3a + power	62.7%	23.2%
4b. As 3b + power	24.0%	7.8%
5. Logistic	54.0%	12.2%

6. Conclusions and Future Research

In this paper, we have addressed investment in renewable and conventional electricity production. The sectors are closely related to each other, as they produce the same commodity. It is also the case, that one sector (conventionals) is currently considerably larger, whereas the other (renewables) is forecast to experience rapid growth. Therefore, the challenge is to model plausibly a possible transition between them. This is related to the ideas about the diffusion of innovations.

Having begun by analysing the characteristics of the standard investment function, we suggested a number of functions. Though a number of these functions (INVFN=2,3,4) had some desirable properties, ultimately we argue that some kind of sigmoid function, such as the logistic (INVFN=5), is the most plausible way to model the relationship between the relative rental rates and the share of investment in electricity.

The logistic function specified above is preferred because (i) it allows the split between renewables and conventionals to be based on rental rates (not the level of the capital stock), (ii) can be parameterised to the initial investment shares, and (iii) it sensibly responds to relative rental rates with respect to the implied investment shares and can be adjusted as appropriate.

Experimentally, we demonstrated the ability of the logistic function to operate in a CGE model, and the performance has been compared to the other functional forms investigated. Though of course, the degree of response from any of the functions is dependent on the arguments employed, for reasonable values the response of the function with respect to shifting investment levels is plausible.

Future research could be done to parameterise this type of logistic function based on more detailed industry information and the assumptions that enter bottom-up energy models. This may involve adjusting the slope of the logistic function, or else it may be that a different shape of sigmoid function was a better fit. Nevertheless, we expect that an approximate sigmoid shape would be retained.

A second future development would be to consider multiple technologies rather than the two (renewables and conventionals) shown here. This could be done with nested logistic functions, i.e. first level choose between renewables and conventionals, second level choose between wind and solar, and so on.

In conclusion, we submit that when dealing with a single commodity, with multiple production methods, it is an improvement on the standard functions to model the investment choice between them based on a sigmoid function that responds to the relative rental rates. The case of the choice between renewable and conventional electricity production is a clear example of an appropriate application of this concept.

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