Allowing for uncertain and asymmetric policy shocks: A CGE analysis of the impacts of on-shore wind farm developments in North East Scotland

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Abstract

This paper explores the extent to which a new on-shore winds sector, gives rise to rural economic benefits taking into account that, *a priori*, the eventual size of the sector (the shock to the model) is uncertain and that the underlying probability distribution of the shock may not be symmetric. A regional CGE model is developed and results from three analyses are compared: one assuming certainty in the size of the sector, one a symmetrically distributed shock, the other an asymmetric distribution of the shock. The findings suggest that the wider rural economic impacts are relatively limited, even when the additional income from the sector is re-invested locally. However the size of impacts is sensitive to the assumed distribution of the shock. In particular, treating the size of the sector as known with certainty appears to over-estimate impacts relative to an uncertain but symmetric size of shock, but underestimate impacts relative to the asymmetric case. The implications for testing the robustness of future CGE model applications are considered.

Keywords: Systematic Sensitivity Analysis; CGE model; onshore renewable energy; asymmetric policy shocks.

1. Introduction

Driven by concerns in energy security and climate change, several new renewable energy sectors have developed over the last decade. These include on-shore and off-shore wind, solar energy, hydropower and a variety of different sectors focussed on exploiting the energy potential of biomass. In most cases, growth has been encouraged and supported by government policies. Many of the new sectors are based in rural areas and policy documents often make reference to the economic benefits that renewable energy generation brings to rural economies. In particular, in addition to their contribution to energy security and environmental goals, the growth in renewable energy is argued to bring new sources of income and employment to areas which tend to have limited alternative opportunities and an overdependence on primary sectors (agriculture, forestry and mining).

Against this background, a number of studies have attempted to measured, *ex ante*, the potential wider economic benefits of renewable energy sectors, the majority using either input-output or CGE modelling frameworks (Trink et al.2012; Caldés et al., 2009; Simola, 2010). In general the results have suggested that the magnitude of benefits varies by type of renewable and, critically, whether the renewable schemes are locally or externally owned (Phimister and Roberts, 2012).

The methodological limitations of input-output models for analysing policy shocks including the impact of new sectors are well known. Similarly there is a growing awareness of the sensitivity of CGE model results to the choice of model closure rules and parameters values. More generally, CGE models are often criticised for being insufficiently validated. In response to such criticism, Systematic Sensitivity Analysis (SSA) is increasingly adopted as standard practice in CGE model applications (see, for example, Keeney and Hertel, 2009;

Hertel et al., 2010). Particularly in regional CGE models where parameters such as trade elasticities are typically obtained from a range of sources, applying SSA techniques is seen as a way of accounting for the model parameter uncertainty.

Monte Carlo Simulation provides the obvious starting point for such SSA. However, the utility of this approach is constrained due to the number of parameters typically treated as jointly uncertain in CGE models. Alternatively, Gaussian Quadrature has provided a range of results and methods for reducing the dimensionality of the problem (DeVuyust and Preckel, 1997, 2007; Domingues and Haddad, 2005). This involves the moments of the joint distribution of the parameters being approximated using a discrete joint probability distribution evaluated over a finite number of points. The simulation values of interest (for example, regional GDP) can then be found by evaluating the model at these points and constructing a weighted average. If the uncertain parameters are assumed jointly independently and symmetrically distributed, then it is possible to apply the Stroud points and approximate the first and second moments of the joint distribution of the parameters. For such special cases, the dimensionality of the problem can be significantly reduced. In particular, with n parameters modelled as random variables, the expected values and variances for model outcomes of interest can be obtained using the Stroud formula from only 2*n separate evaluations of the model (Stroud, 1957).

Although not often considered, SSA can be used to allow for uncertainty in the size of the shock being analysed by a CGE model as well as to test for the sensitivity of model parameters (Horridge and Pearson, 2011). Just as with model parameters, the size of the shock can be treated as a random variable with a given distribution and Gaussian Quadrature used to find nodes and weights which approximate the first thee moments of this distribution. Modelling both parameter uncertainty and prices shocks has been used in recent research to further validate the GTAP model by tracking its ability to reproduce observed price volatility (Beckman et al, 2011; Valenzuela et al, 2007) and to test whether volatility in agricultural commodity markets reduces trade liberalization impacts (Verma et al, 2011). However, to the authors' knowledge, in all cases the random shocks have been assumed to be symmetrically distributed.

In the case of analysing the wider economic benefits associated with a new sector, the size of the sector (the shock to the model) may be unknown. In the case of a new renewable energy sector, it will be determined by the interplay between the supply of developments from private developments and the demand for new developments as reflected through outcomes of the planning process. Further, differences in wind potential across locations, development costs and opportunity costs of capital along with differences in attitudes across locations mean that the distribution of possible outcomes is not necessarily symmetric.

Against this background, the aim of this paper is to explore the extent to which one particular renewable energy sector, on-shore wind, gives rise to rural economic benefits taking into account uncertainty. Analysis focuses on the North East region of Scotland where the growth of farm based on shore wind developments has been extremely rapid over the last decade.

A CGE modelling approach is used and the results from two versions of Systematic Sensitivity Analysis (SSA) (one assuming a symmetrically distributed shock, the other an asymmetric distribution of the shock) are compared to those from the model assuming certainty in the size of the sector that will develop (henceforth referred to as the deterministic version of the model). The findings from all three analyses suggest that the wider rural economic impacts from on shore wind are limited but the relative size of impacts is sensitive to assumptions on the underlying distribution of the shock. In particular, the deterministic model appears to over-estimate impacts relative to symmetric case but underestimate impacts relative to asymmetric case

The following section provides the policy context for the analysis, and presents a simple model highlighting the factors that will influence the equilibrium level of installed wind capacity in a particular region. Section 3 presents an alternative computationally efficient method of conducting SSA when dealing with asymmetrically distributed random variables. It also describes the underlying CGE model, SAM and simulation methods. Section 4 presents the results while section 5 concludes and highlights several areas for further research in relation to CGE model validation.

2. The Policy and planning context

The Scottish government, like many other governments, has ambitious renewable energy targets. At time of writing, the target is to produce the equivalent of 100% of its domestic electricity demand through renewables by 2020. Growth in onshore wind has, to date, contributed most towards achieving this target with capacity growing from around 300MW to over 4300MW between 2003 and 2013 (DECC,2014).

North East Scotland, the case study area for this analysis, is most well known for its links with a non-renewable energy sector – oil – and, since the early 1970s, the North Sea oil sector has played a major role in driving the regional economy. However growth in the renewable energy sector has been strong (Aberdeenshire Council, 2011), particularly in relation to on-shore wind where from a starting point of zero in 2005, 300MW of onshore wind power is at time of writing either operational or has planning consent. The growth has been attributed to the suitability of region for wind energy production, attractive levels of support payments, the relatively positive approach of the local council to wind developments, and the progressive (and innovative) nature of local farmers (Sutherland and Holstead, 2014). Farm household involvement in the wind energy sector has, after a slow start, increased rapidly over the last few years due to the switch in government support from a Renewables Obligations Certificate scheme (which favoured larger externally owner developments) to a Feed-in-Tariff scheme which favours smaller locally owned developments. As a consequence, there are a large number of small wind farms distributed across the region with farmer-owned schemes accounting for an estimated 70% of developments in Aberdeenshire but only 27% of electricity produced.

Although operating within higher level national and regional frameworks, the nature of the planning process in Scotland (as elsewhere in the UK) is such that each individual development is considered on a case by case process. The process is costly, often takes considerable time, and the risk of not getting approval is high.

The ultimate level of installed wind capacity in any region will be determined by the interplay of how the planning process operates and the supply of planning applications from private developers. Together these will determine an equilibrium level of new installed wind capacity. However, differences across locations in cost structures, expectations of future returns and opportunity costs of capital, plus differences in local preferences for wind, means that the ultimate level of installed capacity in the region is highly uncertain. We sketch a simple model below to illustrate this interaction between private developer decisions and the planning process, and the potential key sources of uncertainty for the policy maker.

Associated with each possible location ε within the region, there is potential wind production y^p , with distribution $f\left(y^p,\varepsilon\right)$, while the location parameter is distributed $g\left(\varepsilon\right)$

Each developer must decide whether to make an application for installed capacity y.

Each application attracts a fixed cost of m and faces a given probability of approval q, and net revenue per unit of electricity output, *p*. We assume all approved applications are developed, with differences in development costs (e.g. grid access costs), and opportunity cost of capital accounted for in location specific project costs $c(y,\varepsilon)$ and cost of capital $r(\varepsilon)$ respectively.

For simplicity we consider a two period model with the first capturing the application phase and the second the development and production phase (if the application is approved). At each location, the developer will choose to maximize expected net present value.

$$\underset{y}{Max}\ \ E[NPV] = -m + \frac{q}{1+r(\varepsilon)}\left(p\int_0^y y^p f(y^p,\varepsilon)dy^p + \int_y^\infty yf(y^p,\varepsilon)dy^p - c(y,\varepsilon) \right) \qquad (1)$$

The two terms in the brackets capture the relationship between potential wind output at any location and the level of installed capacity. Analogous to simple inventory models under demand uncertainty: when the potential wind output is below installed capacity, output equal potential wind output, when higher than installed capacity, output equals capacity.

From the first order condition (1), we obtain the following marginal condition which defines the level of capacity planned (and applied for) at each location

$$\frac{qp}{1+r(\varepsilon)}\left(1-\Pr\left[y^d \le y^* \mid \varepsilon\right]\right) = c'(y,\varepsilon) \qquad (2)$$

Integrating over all locations using equation (2) implies the existence of an overall supply, Y, function for applications for the region which is a function of distribution of wind speeds, and the distribution of location specific costs of capital and general costs.

To complete the model we assume the overall probability of a planning application succeeding declines with the level of total applications, and is also dependent a parameter η which captures the preferences of local voters and the politicians

$$q = q(Y,\eta). \qquad (3)$$

The overall supply function, Y, and equation (3) together define an equilibrium level of total planning applications (Y^*) and probability of acceptance (q^*) with the ultimate (saturation) level of installed capacity q^*Y^*

This simple model helps clarify the nature of the uncertainty of the policy shock (from the policy makers perspective), as the ultimate level of installed capacity in a region will depend upon the distribution of potential wind output, capital and other costs plus local political preferences. While the distribution of wind output may be known to policy makers, costs and political preferences are less easy to determine *a priori*. Similarly, it is difficult to argue that the uncertainty of the shock can *a priori* be assumed to be reflected in a symmetric distribution.

In the analysis below we consider the impact of uncertain policy shocks which are both symmetric and asymmetrically distributed. In particular, using SSA, the results from a CGE model within which it is assumed that the final size of the sector is known with certainty (the deterministic model) are compared to those from a model which assumes a random but symmetrically distributed shock and finally to a case when an asymmetric distribution is assumed.

3. Modelling Approach

The rural-urban CGE model

The model used in this analysis is based on the standard IFPRI framework (Lofgren et al., 2002), adapted to make it appropriate for analysis of a regional economy and for the specific purposes of analysis. In particular, the production sectors have been disaggregated to emphasise the agricultural sector and to allow for a shock (in this case the introduction of a new sector) which target the rural part of the region. Three categories of households are recognised: rural, urban and farm households, the latter split further by size of farm. This means that the farm ownership of the new sector can be modelled explicitly. Due to the small size of the region being studied, the model allows for factor incomes to flow across rural-urban boundaries while commodity markets are treated as unified, covering both rural and urban space.

As is the standard approach in CGE models, production is based on the assumption of cost minimising behaviour of producers. A two layered production function is specified where, at the top level, technology is modelled as a CES function combining quantities of value added and aggregate intermediate input and, at the bottom level, intermediate demand is determined assuming fixed input-output coefficients.

Factor earnings from each production activity (including, in the model simulations, earnings from the new onshore wind sector) are distributed to households depending on ownership structure and/or the provision of factor services. Given the importance of farm-based renewables in the region, the new sector is treated as owned and operated by farm households, mapping income from onshore wind into the farm household accounts. The labour market is segmented to distinguish between skilled and unskilled workers with wages and employment levels solved endogenously within the model (Thurlow, 2008). In contrast, capital and land factors are treated as fixed and immobile between sectors.

There are four components of final demand: consumption, investment, government expenditure and exports. Household consumption is modelled as LES demand function of real disposable income. The Government account in the model collects taxes and transfers from other institutions and then uses this income to purchase commodities, provide transfers to other institutions (e.g. households) and to pay for subsidies including to the onshore wind sector. The required government balance is ensured by allowing government savings to adjust endogenously while the external balance is achieved by with fixed levels of investment but allowing for flexible out-of region savings.

Exports (and imports) are determined using the Armington approach. In other words, regional market demands are assumed to be for a composite good made up of a CES-determined combination of regional output and imports where the two are imperfect substitutes. Similarly, regional output is derived by aggregating across all potential regional sources of supply and then split into that consumed within the region and exported using a CET function.[1]

The model is restrictive in terms of its ability to model potential feedback effects between the region and the wider UK and international economy. In particular, the subsidies given to

[1] Further details of the model are given in Phimister and Roberts (2012).

support the new renewable sectors are treated as exogenous (from the UK government) and there is no account taken of possible feedback effects from this in the form of increased local taxes. The model also ignores the impact of the increased electricity generation on the wholesale UK electricity market and on fossil fuel generation. These may give rise to negative displacement and price effects at UK level which would feedback into the region. While not ideal, the limitations of the model are justified in this case by the small size of the region and the limited size of shocks being analyzed.

The North East Scotland Social Accounting Matrix (SAM)

A SAM consistent with the model structure was constructed with a base year of 2005, providing a numerical account of the flow of income in and around the region immediately prior to the development of the onshore wind sector. The construction process involved an initial mechanical regionalisation of Scottish input output tables, based on employment quotients, and the subsequent improvement and/or further disaggregation of initial estimates using information on key sectors. The final balanced SAM was generated using cross entropy methods (Robinson et al., 2001).

The base year SAM distinguishes 48 production sectors, distinguishing farms by size (those 40 ESUs or over classified as large, the remainder small) and farm type (crop, livestock and "other"). Households resident in Aberdeen City local authority area are classified as urban, the remainder (excluding farm households) as rural, and farm households split according to the size of the farm. Table 1 provides summary information on the case study region as derived from the SAM.

Table 1: Summary information from the North East Scotland SAM, 2005.

		North East Scotland
GDP (£m)		8,852
Rural Share (%)		*34*
Urban Share (%)		*66*
Sectoral contributions to value added (£m):		
Rural Area	Agriculture	83.5 (2.8%)
	Forestry	9.0 (0.3%)
	Fishing	50.5 (1.7%)
	Other Primary	87.8 (2.9%)
	Food processing	141.6 (4.7%
	Wood processing	66.2 (2.2%)
	Energy	48.8 (1.6%)
	Other Secondary	678.9 (22.6%)
	Tertiary	1,830.2 *(61.0%)*
Urban Area	Primary*	601.9 *(10.3%)*
	Secondary	890.5 *(15.2%)*
	Tertiary	4,363.3 *(74.6%)*
Total household income (£m)		7,186
Urban HH (%)		*52.5*
Rural HH (%)		*45.9*
Small farm HH (%)		*1.0*
Large farm HH (%)		*0.5*
Total value of exports(£m)		10,902
Total value of imports(£m)		9,590

*Includes oil extraction

Simulations

To undertake an ex-ante evaluation of the potential impact of onshore wind on the North East Scotland economy, a new renewable energy sector is introduced into the model based on the costs and revenues given in Table 2 below. The analysis focuses on the medium to long run impact of the new sector (the construction phase is not modelled) where farm households are the residual claimants on factor income after capital costs have been paid.

Table 2: Typical annual costs and revenues per MW Installed capacity (£m 2005)

	per MW Installed Capacity Wind
Operating and Maintenance Costs	0.050
Fuel Costs	
Annual Capital Costs	0.135
Annual Income[1]	0.076
Total Revenue[2]	0.260

[1] Figures for Wind based on Bell and Booth (2010) for a single 0.8MW Turbine.. Capital costs annualised assuming a 20 year loan at 6% interest.
[2]Based on the deflated 2010 ROC returns and a capacity factor of 32% for wind.

As there is limited information on the commodity and factor composition of operating costs, operating and maintenance costs are allocated over skilled and unskilled labour categories, with small proportions of these costs allocated to commodities which were thought to be demanded, i.e. insurance, construction, transport, other services and other manufacturing. The CES elasticity of substitution is set equal to the value used for the other production sectors and then the value added function parameter was obtained consistently with the calibration process for the other sectors.

The annual gross revenue of the new wind sector is taken as £260K per MW installed in 2005 prices. Broadly consistent with the typical Renewable Obligations Certificates (ROC)[2] values relative to the wholesale electricity prices between 2005-2010, half the revenue is assumed to be derived from subsidy payments, with the remainder arising from electricity sales. Annual financing costs and income are treated as the factor payments to capital specific to the onshore wind sector.

For each of the simulations, the model is first calibrated to the 2005 case and then the impact of adding the new onshore wind sector simulated based on the cost and revenues outlined above under two alternative scenarios. In the first, investment (and activity specific capital stock) is exogenous, thus extra income associated with the new renewable sectors is received by farm households and then allocated primarily to consumption. This is henceforth labelled the “Consumption” scenario. In the second scenario, to capture the possible effects of re-investment by farm households, the increased factor income from the new renewable sector is used to increase capital stock in agricultural activities. To implement this, we take the capital factor payments of the onshore wind sector from the first set of simulations as the value of additional investment in the economy (i.e. after allowing for interest capital repayments). The resulting increase in capital stock is estimated by assuming that the

[2] ROC are a form of Green Certificates, and, prior to the introduction of FiTs, were the primary mechanism for supporting the renewable energy sector in the UK.

published values for gross fixed capital formation in agriculture are steady state values, that is they maintain capital stock at 2005 values. The factor income allocated to extra investment in each scenario is then assumed to increase the steady state capital stock relative to these base GFCF values with new capital stock allocated across agricultural sectors in proportion to base year capital factor payment levels.

Systematic Sensitivity Analysis

As noted above, a potentially significant limitation in Stroud implementation of SSA is the assumption of symmetry of all the underlying distributions. Based on the discussion in section 2, there seems no *a priori* reason for assuming a symmetric distribution in the case of the onshore wind sector. An alternative to using specific theoretical results which are applicable for symmetric distributions only, GQ weights and evaluation points for any general distribution can be derived from a suitably defined linear programme (DeVuyst and Preckel, 2007) .

DeVuyst and Preckel's (2007) general approach to finding a solution to the associated LP problem for the GQ is first to define the underlying distribution $f\left(X\right)$, and obtain the associated known moments which define the right hand side of the LP constraints. Following this, the approach involves finding a large number of points x_{ik} within the domain of the integration and c) solve the associated LP problem. However, to the best of our knowledge this approach has not been implemented in CGE models to allow for non-symmetric distributions. While the appropriate linear programme is straightforward to define, its size expands rapidly as the number of parameters involved increases (Arndt et al, 2006). This limits its potential usefulness for general SSA involving a large number of parameters although linear dependencies between the constraints mean that quadratures can be found with many fewer points than the number of LP constraints.[3]

Even for problems where a limited variables are to be considered random and where it is feasible to use Monte Carlo, the reduction in dimensionality provided by the quadrature is computationally attractive. However, a potential issue, at least in the general case where the distributions of the random variables in *X* are not independent, is that finding the initial values which define a quadrature and can be used as the basis for the LP can be difficult.

We circumvent this potential difficulty by a simple adaption of the DeVuyst and Preckel procedure. The first step proceeds as before, i.e. the distribution is defined and appropriate population moments constructed. Following this, a number of random samples from this distribution are drawn and used to calculate the associated sample moments for this data. Then, rather than the actual population moments, we use the sample moments to define the right hand side constraints of the system (2) while the drawn random samples define the left hand side values to complete the constraints of the linear programme. By definition, the solution including all points with equal weights, is guaranteed to be feasible in this problem. One obvious limitation of this approach is that the quadrature obtained is now not defined for the population moments but rather is an approximation to them. However, arguably the extent of the errors induced are likely to be small and can be tested. [4]

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[3] For example, experimentation for a case where 23 parameters were allowed to vary, the LP has more than 2500 constraints but a quadrature with 1000 points was found.

4 As an indication, we calculated the average absolute relative errors for the analysis reported in section 4 and these were found to be less than 0.12 percent for the expected value and less than 0.23 percent for the second moment.

We apply this amended quadrature approach to the North East Scotland CGE model with degree 3 GQ weights and points constructed for an SSA for the size of the new wind sector only. Three cases are considered. In the base case it is assumed the size of the sector is known with certainty to lead to 500MW output. The results from this deterministic model are compared to the results from a) a model where the size of the sector is assumed symmetrically distributed and b) a model where the shock has an extreme left triangular distribution with a minimum value of 300MW and a maximum value of 900MW. In both cases the expected value and variance of the distributions were maintained equal to the base case.

4. Results

Table 3 reports the overall impact on GDP of the new onshore wind sector as estimated under each of the three alternative shocks to the model: The deterministic shock where the size of the new sector is taken as known with certainty as being 500MW, the symmetric shock where the shock is treated as a random variable symmetrically distributed above and below the expected value of 500MW, and finally a left triangular asymmetric shock, distributed with a minimum value of 300MW and a maximum value of 900MW again with an expected value of 500MW. The table reports both the absolute change and percentage change in GDP from base year levels. For the two random shocks, the results come in the form of point estimates of the particular endogenous variable shown along with their associated coefficients of variation (CV) shown in brackets. Low CVs indicate results in which we can have confidence and vice versa.

Table 3: Comparison of GDP impacts

	Deterministic		Symmetric		Asymmetric (Left triang.)	
	Consumption	Investment	Consumption	Investment	Consumption	Investment
Change in GDP (£million)						
Total	100.21	116.694	97.119	112.621	106.443	122.841
			(0.405)	(0.376)	(0.340)	(0.312)
Rural	108.574	128.056	105.235	123.565	115.334	134.704
			(0.405)	(0.373)	(0.340)	(0.312)
Urban	-8.364	-11.362	-8.116	-10.944	-8.892	-11.863
			-(0.403)	-(0.340)	-(0.340)	-(0.279)
Percentage change from base year values						
Total	1.132	1.318	1.097	1.272	1.202	1.388
			(0.405)	(0.376)	(0.340)	(0.312)
Rural	3.623	4.273	3.512	4.124	3.849	4.495
			(0.405)	(0.373)	(0.340)	(0.309)
Urban	-0.143	-0.194	-0.139	-0.187	-0.152	-0.203
			-(0.403)	-(0.342)	-(0.342)	-(0.276)

(Values in parentheses are Coefficients of Variation)

As anticipated, in all cases, if income from the new sector is re-invested in the economy then total GDP benefits are higher than they would be otherwise although, even in these cases, the total GDP effects are relatively small in relation to the size of the economy. The distribution of GDP effects across rural-urban space follows the same pattern across all three versions of the model with rural GDP expected to rise, urban GDP fall slightly. The results indicate that while the overall impact in all cases is small relatively, the underlying distribution of the shock does matter. In particular, the deterministic model appears to over-estimate impacts relative to symmetric case but underestimate impacts relative to asymmetric case.

Table 4 reports the welfare effects associated with each of the simulations where welfare is measured in terms of the equivalent variation (EV), the monetary equivalent of how much better off (or worse off) households are in consumption terms after the introduction of the new sectors compared to their unobserved base year welfare level (Blonigen, et al., 1997).

Table 4: Welfare impacts: Percentage change in EV from base year consumption

	Deterministic		Symmetric		Asymmetric (left triang.)	
	Consumption	Investment	Consumption	Investment	Consumption	Investment
Urban Households	-0.732	-0.059	-0.712 -(0.409)	-0.061 -(1.115)	-0.78 -(0.346)	-0.075 -(0.933)
Rural Households	-0.792	-0.003	-0.769 -(0.407)	-0.008 -(7.625)	-0.843 -(0.344)	-0.02 -(3.250)
Farm h'hold small farms	19.993	9.191	19.384 (0.399)	8.643 (0.183)	21.221 (0.336)	9.103 (0.109)
Farm h'hold large farms	75.812	10.932	73.506 (0.399)	10.281 (0.184)	80.475 (0.336)	10.83 (0.110)
Non-profit insit.	-0.645	-0.128	-0.627 -(0.407)	-0.126 -(0.619)	-0.687 -(0.344)	-0.143 -(0.531)
Total	-0.174	0.098	-0.17 -(0.435)	0.087 (0.494)	-0.187 -(0.374)	0.082 (0.610)

(Values in parentheses are Coefficients of variation)

The development of a new wind sector is shown to give rise to negative welfare effects for all but farm households. In contrast, farm households particularly those with large farms, benefit significantly from the development of the new sectors. However, the EV values in Table 4 indicate that both the total and rural results under the on-shore wind reinvestment scenario are far from certain. Similar to the GDP results shown in Table 3, the results above suggest that underlying distribution of the shock matters somewhat with the (absolute) size of the shocks smallest in the symmetric case and largest in the asymmetric case.

5. Discussion

This paper explores the extent to which one particular renewable energy sector, on-shore wind, gives rise to rural economic benefits taking into account both a) that the eventual size of the sector is uncertain (a random variable) and b) that the underlying probability distribution of the shock is unknown and may be asymmetric. The findings suggest that the wider rural economic impacts from on shore wind are limited but the relative size of impacts is sensitive to the underlying distribution of the shock. In particular, the scenario where the shock is treated as deterministic appears to over-estimate impacts relative to uncertain but symmetric shock but underestimates impacts relative to the asymmetric case.

At a general level, the results emphasise the need to extend SSA to allow for uncertain policy shocks as well as uncertainty in terms of parameter values. It also highlights the importance of allowing for the possible asymmetric nature of these shocks in CGE applications.

In relation to the modelling the impacts of the onshore wind sector, there is potential to extend the underlying model so as to allow for potential cumulative effects in the planning process. In particular, due to the negative landscape impacts of onshore wind developments and planning regulations which restrict developments within certain distances of places of residents, the likelihood of any particular development being approved by planning may be conditional on the size of the sector when the application is made. It would therefore be useful to include in the model a more comprehensive representation of the planning process. This would provide a better understanding of the dynamics of the interactions between planning and applications, interactions which determine the ultimate size of the sector in the regional economy.

Finally, the proposed adaptation to DeVuyst and Preckel's (2007) GQ approach (using sample moments to initiate the linear programming) provides a computationally-efficient means of allowing for asymmetry. Developing this approach to allow for distributions of correlated random variables would be another fruitful area for future research.

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