Comparative Analysis of Emerging Green Certificate Markets from a Computable General Equilibrium Perspective

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ABSTRACT
Whether using market mechanisms to allocate green certificates in various countries is an optimal solution for stimulating green electricity production represents a question proposed by numerous recent comparative analyses, with opinions being split. Our paper proposes a differing perspective, employing modern computational economics techniques in order to study if general equilibrium is achievable, nationally and internationally, and how it compares with the non-market steady state. We analyse the field, determining exogenous and endogenous factors of influence that we cast into functional relationships via econometric estimation. Subsequently, we study four multi-period general equilibrium models, recursive and non-recursive, solving the latter ones via a Johansen/Euler method for simultaneous all-year computation. General equilibrium is shown to be achievable but dependent on country specific conditions, with optimality being relative in a globalised context. In closing, we present a case study focused on providing useful guidelines for future international marketing efforts in this domain.

KEYWORDS: *computational economics, general equilibrium, globalisation, multi-period model, optimising behaviour.*

JEL CLASSIFICATION: *C68, M39.*

INTRODUCTION

Diminishing and ultimately eliminating the damaging impact traditional industrial activity has upon the surrounding environment has been at the centre of numerous debates and investigations for the past decades. Somewhat unsurprisingly, the energetic sector has been identified as one of the primary areas in which intervention would generate a significant effect. One of the more prominent initiatives is the one put forth by the Commission of the European Union in its White Paper on Renewable Energy (European Commission, 1999). Out of the numerous mechanisms that have been designed along the way, from strict governmental coercion to use of incentives to stimulate the move to environmentally friendly technologies, the relatively recently introduced “green certificates” show a notable amount of promise in terms of stimulating the penetration of green electricity into the

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electricity market. This is in no small part due to their potential to be allocated via pure market mechanisms, rather than arbitrarily by one authority or another. In brief, electricity producers create green certificates as they produce electricity employing renewable energy sources. Demand can be generated by different actors, from consumers to the government itself (either indirectly, through coercion, or directly, through purchase). Considering that the electricity supply chain is composed of 3 categories of actors, namely generators, distributors and suppliers, *Table 1* synthesizes potential distortions (Schaeffer et al., 1999). It's worth noting that in spite of the promise, some economists are sceptical in their regard, a notable example being Haugneland (2004).

Some amount of formal research has been invested in the design and study of a market for green certificates, especially since countries in northern Europe have moved towards implementing one. We'll note work presented in Morthorst (2000; 2003), Jensen and Skytte (2002), Soderholm (2008) or Marchenko (2008). The latter is somewhat related to our work, as it seeks to study the equilibrium for a green certificate market using a mathematical model, arriving at the conclusion that green certificates represent suboptimal means for minimizing the impact of energy production on the environment, whilst also outlining that a mix between traditional and green sources is the likeliest to generate an economy wide optimum.

Table 1. Market distortions per level of obligation

Level of obligation	Green Certificate system introduced at national level only	Green Certificate system introduced European-wide with varying degrees of liberalisation
Generator	International competitive disadvantages because other countries have no target obligation.	International comparative disadvantage because of varying degrees of liberalisation.
Supply	Possibility of consumers to by-pass the obligated level. International competitive disadvantages because other countries have no target obligation.	Possibility of consumers to by-pass the obligated level. International comparative disadvantage because of varying degrees of liberalisation.
Consumer		(International comparative disadvantage because of varying degrees of liberalisation).

Source: adapted from Schaeffer et al. (1999), p. 11

We approach the problem from a different angle: we treat it as a Computable General Equilibrium (henceforth CGE) one, and we also account for international effects, rather than focusing on the energy sector from a single country in isolation. This juxtaposition allows us to study not only intra-country but also inter-country regional aspects, as well as evaluate the dynamic behaviour of the model we propose. Moreover, using a CGE model allows us to leverage modern computing techniques in order to rapidly evaluate a high number of simulation steps, in the case of multi-period forecasting, as well as use more complex functional forms.

In our analysis, we chose to study two somewhat dichotomous market contexts, namely the already established markets found in northern European countries like Sweden or Norway and, respectively, the emerging Romanian market. Beyond common aspects, like production volumes and pricing at equilibrium, we were also interested in evaluating more subtle aspects, like the impact of different consumer cultures on consumer reactions to policy changes.

1. MODEL DESCRIPTION

We will briefly discuss the structure of a CGE model, as well as the Johansen/Euler method we use for solving it. The interested reader is directed to the extensive treatment present by Dixon and Parmenter (1996). We reuse notational conventions employed there.

A CGE model can be used both for single period comparative static analyses as well as for multi-period forecasting. It is fully described by the following 6-tuple:

- Input-output data;
- Elasticity parameters;
- Theoretical specification;
- Solution algorithm;
- Result interpretation.

We now turn to presenting the algorithm proposed in Johansen (1960). Let $V \in \Re^n$ be the vector that describes the equilibrium state of the model, or, otherwise said, it is a solution for:

$$\mathrm{F}(\mathrm{V}) = 0, \mathrm{F} : \Re^{\mathrm{n}} \to \Re^{\mathrm{n}} \qquad (1)$$

F is assumed to be differentiable, and $n > m$, therefore $n - m$ variables are exogenous by rapport with the model. Let V^1 be a known initial solution satisfying (1). We can rewrite (1) as:

$$F(V_1, V_2) = 0 \qquad (2)$$

where $V_1 \in \Re^m$ is the vector of endogenous variables and $V_2 \in \Re^{m-n}$ is the vector of exogenous variables. By totally differentiating (2) and imposing the condition of remaining at an equilibrium we arrive at:

$$F_1(V^1)dV_1 + F_2(V^1)dV_2 = 0 \qquad (3)$$

where F_1 and F_2 are matrices of *F*'s partial derivatives evaluated at V^1. In this context, a single step Johansen/Euler approximation becomes:

$$dV_1 = B(V^1)dV_2 \qquad (4)$$

where

$$B(V^1) = -F_1^{-1}(V^1)F_2(V^1) \qquad (5)$$

If $B(V^1)$ can be evaluated, we have thus obtained insight how endogenous variables are affected by movements in exogenous variables, around the equilibrium state. Whilst there are a number of aspects of the algorithm that are more than worth an in-depth discussion, given the spatial constraints we will contend with fleshing out the magnitude and impact of approximation errors.

Let us consider that $B(V^1)$ contains the partial derivatives of the endogenous variables V_1 with respect to the exogenous variables V_2, evaluated at V^1. Otherwise said, it is the Jacobian matrix of a solution function G. By way of consequence, evaluating dV_1 through (4) only provides a first order approximation of the impact on the endogenous variables. Let $(dV_1)_{true}$ be the exact vector of coefficients assumed by the model and $(dV_1)_1$ the result of (4). Then, we have:

$$(dV_1)_{true} = G(V_2^1 + dV_2) - G(V_2^1) = B(V^1)dV_2 + HOT = (dV_1)_1 + HOT \tag{6}$$

with HOT being the vector of higher order terms in the Taylor series expansion around V^1. The magnitude of the approximation error clearly depends on the magnitude of dV_2, and the way to ensure that the former is as close as possible to the true values is to use a multi-step computation. For example, using a two-step computation, in the first iteration we compute:

$$(dV_1)_{1,2} = B_{1,2}(\frac{1}{2}dV_2) \tag{7}$$

where $(dV_1)_{1,2}$ represents the approximation for the impact of introducing a half-shock into the exogenous variables and $B_{1,2}=B(V^1)$ as defined in (5). We use the result of the first step computation to re-evaluate B:

$$V_{1,2} = \left[V_1^1 + (dV_1)_{1,2} V_2^1 + \frac{1}{2}(dV_2)\right] \tag{8}$$

$$B_{2,2} = -F_1^{-1}(V_{1,2})F_2(V_{1,2}) \tag{9}$$

thus becoming able to compute:

$$(dV_1)_{2,2} = B_{2,2}\left(\frac{1}{2}dV_2\right) \tag{10}$$

which represents the effect of the remaining half of the exogenous variable shocks. From (7) and (10) we can compute the two-step approximation:

$$(dV_1)_2 = (dV_1)_{1,2} + (dV_1)_{2,2} \tag{11}$$

Conveniently, two step approximations tend to suffice when dealing with quadratic functions, which fit our use case well. However, for non-quadratic forms more steps are required – for a more extensive discussion of such aspects we point the interested reader to texts like Dahlquist et al. (1974) or Dixon et al. (1982). The main relevant insight is that the structure and solution algorithm we have chosen for our model is capable of providing adequate steady state solutions, when properly tuned.

In our model, we rely on data provided by relevant authorities for the input-output database. We split the energy sector into 3 types of domestic producers, 2 types of investors, a representative consumer and an aggregate foreign attractor of certificates. The industries are considered to be profit maximizers, with green certificates having a positive net effect on the value of the profit function $\pi\left(\frac{\partial \pi}{\partial green} > 0\right)$. In their role as users of resources, they are price takers (none of the industries can dictate the price of primary factors, namely labour and capital).

We assume a CES production function and vary the parameter to particularise per each producer type, with constant returns to scale being considered:

$$Z_j = A_j\left(\sum_i b_{ij} X_{ij}^{-p_j}\right)^{-\frac{1}{p_j}} \text{ with } \sum_i b_i = 1$$

The representative consumer maximises a nested utility function subject to aggregate-expenditure constraint, with the top-level utility function being of the Klein-Rubin type:

$$U = \sum_{i=1}^{n} b_i \ln(q_i + \gamma_i) \text{ with } \sum_i b_i = 1,\ q_i - \gamma_i > 0$$

and the second level allowing for CES substitution between sources of energy. We differentiate between the capital used for creating green energy and respectively traditional energy, each having different costs and being non-substitutable in the production process. This allows for studying investor orientation as well as the assignment of investment resources per capital category. Ultimately, at equilibrium we evaluate the throughput in terms of energy in general, energy per category, unit price, capital stock and breakdown and consumption patterns.

Through econometric analysis we determine relevant parameters for our functions. Given the extensive size of the model (more than 30 equations, more than 30 variables), we forego presenting it in extenso. We used GEMPACK as supporting software, as it is one of the leading solutions for CGE problems. For some of the analysis we manually calculated the Jacobians associated with the Johansen/Euler iteration, allowing for insight into differential dynamics in an analytical form.

2. CASE STUDIES

In this section we will employ the model we developed in analysing separate markets, in order to outline their behaviour under different circumstances. Each of the markets is characterised by peculiarities in terms of consumption culture and implicitly consumer behaviour, therefore the dynamics are heterogeneous between the studied environments. Our analysis also covers specific aspects dealing with direct government implication and the degree of market liberalisation.

2.1. Comparative statistics: Norwegian and Swedish green certificate markets

The Norwegian and Swedish green certificate markets are arguably mature, with the latter being introduced in 2003 and the former in 2006. Moreover, they are co-integrated as part of a larger, Nordic market. This means that studying the impact of different policies is somewhat more interesting in their case, as the consumer base is likely to be well versed in the merits of green electricity, as well as the workings of the green certificate mechanism.

Considering a single-period static model, we were interested in studying how much of the cost of producing green energy the consumers were willing to support explicitly. Also, by arbitrarily introducing pseudo-protectionist measures, like discriminate pricing for non-local certificates or controlled government intervention aimed at affecting the equilibrium pricing we studied how being part of a larger, trans-national market impacts dynamics. Another potentially interesting avenue of study is the one tied to the removal of green certificates, which we can simulate by adjusting the restrictions of the model. Finally, by altering the behaviour of the representative investors through modifying their payoffs per investment type, we studied what sort of incentives could be introduced in order to support the accumulation of capital aimed at producing green energy.

The results offered by our model line-up with those presented in prior papers. First of all, given the current cost structure associated with green energy production (which, in the absence of significant scientific breakthroughs isn't likely to fundamentally change in the near future), Norse consumers are ready to directly support up to 25% of it. Placing a higher burden on the consumer triggers a reduction in energy consumption. Given that Norway appears to have a slight comparative advantage versus Sweden, the addition of protectionist measures impacted its producers more, with their product mix slightly shifting in favour of traditional and arguably cheaper types of energy, which caused an overall reduction in production of energy from renewable sources – this was to be expected as production was above the compulsory minimum put in place by the Norwegian government.

Completely removing the green certificate mechanism had an interesting effect, in that overall the green energy throughput wasn't severely affected – this can be explained by capital already invested/involved in the production of green energy can't be repurposed. The investors, however, appeared to have a more intense reaction, with a notable reduction in investments directed at green energy production. Based on this behaviour, we then explored how governments in the two countries could more effectively stimulate investors do direct funds to green energy production. As such, we iteratively modified the form and parameters of the investor utility functions. The results we achieved suggest that a minimum guaranteed payoff associated with investing in energy based on renewable sources (for example, a lump sum handed by the government to those who chose to invest in green energy) is a very effective incentive strategy.

2.2. Dynamic forecasting: Romanian green certificate market

Moving to the Romanian case, we were preoccupied by how future trajectories are conditioned by current state. Unlike the other countries, Romania's green certificate system is only starting, with both consumers and producers being somewhat unfamiliar with such practices. We treated the model as a multi-period dynamic one, evaluating the number of iterations needed for convergence to equilibrium, as well as the state characterising that equilibrium.

The fastest convergence was achieved when the amount of green energy taxation directly imposed on the consumer was kept at most equal to 10%. This is explained by the higher sensitivity of Romanian consumers by rapport with explicit taxation. Another interesting dynamic was attached to removing the significant subsidies currently offered to certain categories of consumers: there was a significant reduction in consumption at equilibrium, with prices following a downward sloping trend.

CONCLUSIONS

In this article we have treated the problem of using market mechanisms to handle green certificate distribution as a CGE one. We have thus constructed a model which allowed us to perform an extended analysis, which took into account both common aspects, like prices set at equilibrium and demand or supply associated with it, as well as more nuanced ones, for example the impact of governmental decisions or, more importantly, the way in which the peculiarities of consumers associated with a national space impacts behaviour when faced with similar shocks. We believe the latter to be of significance for planners and entities interested in introducing a green certificate market into one country or another, based on a foreign model and, by extensions, to international marketers.

Our specific conclusions can be synthesized in the following list:

1. The way prices and governmental decisions come about in different European States has the potential to limit the development the green certificates market;
2. Distortions are expected in situations in which feed-in regulations or a tendering system are combined with an international tradable green certificates system;

3. Most EU countries have some kind of policy supporting renewable sourced electricity (RES-E) but Tradable Green Certificates (TGCs) are only implemented in a few states;

4. Different sources of demand for green certificates (voluntary demand of customers for 'green electricity' an obligation from the Government) generate different behaviours in different markets.

We believe that our model, whilst comprehensive, is not all encompassing. In fact, its scale is reduced in the context of other CGE models. Our future work will focus both on extending and refining it, moving to more complex functional forms, using a more granular segmentation of producers, consumers and investors, and studying more intricate, cascading effects of shocks like market liberalisation or the introduction of trans-national certificate trading.

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