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Promotion policies for renewable energy and their effects in Taiwan

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ABSTRACT

Taiwan is an interesting case in bioenergy development, and its government has employed several subsidies to promote bioenergy, such as released land compensation and energy crop subsidies; however, how farmers respond to these economic incentives is not clear. The study employs the concept of "Big Data" by incorporating data on the input–output of crop production, demand elasticities, international trade and tariffs, processing technologies, commodity prices and energy prices for more than 85% of Taiwanese agricultural and forest commodities. The study first utilizes a mathematical programming model to examine the effectiveness of these policies in terms of bioenergy production and GHG (greenhouse gas) emissions reduction and then applies the dynamic structural equation model to analyze the interactions among important input and output factors, such as social welfare, energy prices, bioenergy production, GHG emissions and CO_2 trade prices. The results show that (1) the GHG price is more effective than the coal price in the sense of reducing the ethanol production; (2) the gasoline price has a negative impact on contemporary electricity production while the coal and GHG prices have positive impacts; (3) current ethanol production has a negative influence on current GHG emissions reductions; and (4) the gasoline price, coal price, GHG price and GHG emissions reductions have a significant positive impact on contemporary welfare.

1. Introduction

Sustainable development is an important issue because it ensures that future generations will have access to resources for the progression of civilization. The environment is one type of resource, and its degradation is regarded as an inefficient resource allocation. One important factor degrading the environment is the use of fossil fuels, which accelerate the greenhouse gas effects that may make the environment unstable (IPCC, 2007; McCarl and Schneider, 2003), leading to challenges for future generations. Therefore, countries should adopt sustainable and clean production technology to correct resource misallocation and ensure intergenerational fairness. For this reason, finding alternative energy sources that not only reduce the use of fossil fuels but also mitigate climate change is attractive for many countries. Renewable energy is one such attractive possibility because it takes sustainable development and clean production into account simultaneously.

Bioenergy is one type of renewable energy that Taiwan has intensively studied (Chen and Chang, 2005; Kung et al., 2013; Tso and Su, 2009) for several reasons. First, due to global competition in agricultural markets, Taiwan's agricultural industry has been losing its competitiveness, and a substantial amount of cropland has been released, which provides the potential land for planting renewable energy resources. Second, unlike the instability of thermal or hydro power, bioenergy is produced using agricultural commodities, indicating that domestically cultivated bioenergy feedstocks could provide stable sources of renewable energy production. Third, bioenergy offsets greenhouse gas (GHG) emissions. Because Taiwan is vulnerable to the rising sea levels that are the result of climate change, reducing emissions through bioenergy could be an important and attractive program for the Taiwanese government. The production of bioenergy from released land, however, is not a simple issue. The development of the bioenergy industry may bring about various issues, such as (1) government subsidies for both energy crop plantation and bioenergy production: in the beginning stages, economic incentives for farmers may be necessary to encourage them to convert released land or current cultivation patterns into energy crop plantations; (2) GHG emission cutoff targets: because climate change mitigation brings potential benefits to all of society in terms of reduced damage from potential extreme events, some environmental policies may be initiated to reflect the reduction in GHG emissions associated with bioenergy

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production; (3) efficient resource allocation in terms of land, labor and capital: bioenergy development is quite expensive and involves substantial changes in land competition and labor choice, and the social optimum associated with bioenergy production should therefore be achieved without decreasing the consumer surplus and producer surplus in the agricultural and energy sectors; and (4) market responses: the price and supply of fossil fuels are subject to the influence of international economic and political issues. Domestically produced bioenergy could reduce dependence on uncertain and volatile global energy markets.

This study contributes a policy cornerstone by not only providing information on bioenergy development and environmental effects in terms of renewable energy production and climate change mitigation but also by examining the relationships among various influencing factors. Because social welfare is affected by bioenergy production under market operations, this study establishes a dynamic structural equation model to analyze the directional influence (or causal relationships) of multiple variables. The combination of direct and indirect impacts makes the effect of gasoline prices on social welfare debatable. The results are helpful for policy makers in deciding agricultural and environmental policies, including government subsidies, released land payments, environmental protection and energy substitutes.

2. Literature review

Many studies regarding renewable energy have been undertaken worldwide (Arvizu, 2008; Fargione et al., 2008; Lehmann, 2007; McCarl, 2008; McCarl et al., 2009; Searchinger et al., 2008). Campiche et al. (2010) show that the cost of cellulosic ethanol in the US agricultural sector will fall in the long run because cellulosic ethanol production will significantly increase as conversion technology improves. Farmers could make more money with sales of corn stover, leading to higher corn production. Bioenergy not only makes energy sustainable but also mitigates global climate change by reducing GHG emissions. McCarl and Schneider (2000) use an economic model to evaluate the carbon displacement potential of agricultural feedstocks. McCarl (2008) also shows that emission offset rates for electricity are higher than other forms of bioenergy because of low transformative energy requirements. In addition to conventional bioenergy technology, one technology called pyrolysis has a higher rate of both electricity conversion and GHG offsetting. If biochar (by-product of pyrolysis) is applied as a soil amendment rather than being used for electricity generation, GHG emissions will be further reduced (Gaunt and Lehmann, 2008; Lehmann, 2007; Lehmann and Joseph, 2009).

Among the numerous bioenergy studies, only a few pertain to Taiwanese conditions. Scholars at the Taiwan Institute of Economic Research (TIER) suggest that Taiwan can use multiple energy crops to produce biodiesel to improve Taiwan's current reliance on foreign energy (Tso and Su, 2009). They also examine the energy input/output ratio of corn, sweet sorghum and sugarcane to test the consequent environmental benefits in terms of GHG emissions. Even with positive figures on both energy production and GHG reduction, people question whether Taiwan has sufficient cropland to produce renewable energy. Taiwan had a total of 68,000 ha (hectare) of idle cropland in 2001, which increased to approximately 280,000 ha after Taiwan joined the Word Trade Organization. To ensure farmers' basic living standards in the face of global competition in food markets, the Taiwanese government subsidizes NT$ 90,000 per ha on released land (Chen et al., 2011). Study results show that if released land is fully utilized, approximate 3% of the total gasoline used in Taiwan could be replaced by ethanol. Kung et al. (2013) examine competition between electricity and ethanol and among energy crops. In most cases, sweet potatoes are the main source of bioenergy production, with switchgrass as a possible feedstock alternative when coal prices are high. To encourage farmers' participation in energy crop plantation, despite the NT$ 90,000 released land payment, an additional NT$ 50,000 subsidy per ha is set by the Taiwanese government. Based on these supporting policies, a bioenergy industry may be established in Taiwan. This study employs several bioenergy technologies, such as ethanol, co-fire and pyrolysis (fast pyrolysis and slow pyrolysis), to examine how these policies affect the net bioenergy production and GHG offset.

Structural equation modeling is a general term that is used to describe a family of statistical methods designed to test a conceptual or theoretical model (Goldberger, 1972). Causal modeling, a major application of structural equation modeling, hypothesizes causal relationships among variables and tests the causal models with a linear equation system. Structural equation modeling has been used previously to study renewable energy. For example, Rao et al. (2006) use structural equation modeling to show how environmental indicators correlate with the environmental performance of small and median enterprises in the Philippines. Chien and Hu (2008) employ structural equation modeling to analyze the effect of renewable energy on GDP in 116 economies. Huijts et al. (2014) examine the determinants of the intention to act toward a local hydrogen fuel station using structural equation modeling based on the technology acceptance framework. Additionally, structural vector autocorrelation (VAR), an extension of structural equation modeling, has been widely used. Tiwari (2011) uses the structural VAR to analyze the dynamics of renewable energy consumption, economic growth and CO_2 emissions. You (2011) employs structural VAR to study the long-term dynamic relationship between China's energy consumption and economic growth. Silva et al. (2012) analyze how renewable energy sources of electricity generation affect GDP and CO_2 emissions.

3. Mathematical programming and analysis

3.1. Data description

To properly evaluate this problem, data is the most essential part. This study adopts the idea of big data that are usually used in the commercial and computer industries by including various sources of data for prospective analysis. Bioenergy and sustainable development can also incorporate this concept as well. With various characteristics engaged in agricultural and bioenergy production processes, the concept of big data can be accommodated by including all of the components involved in production, transportation, storage and utilization of commodities, the production of bioenergy, government regulations and environmental consequences, all of which may be adjusted through market operations. To better reflect reality, the dimensionality of the data used in this study includes (a) quantitative variables such as fertilizers, seed, irrigation, chemical applications, mechanics, labor, land, commodity prices, price elasticity and crop outputs; (b) quantitative variables such as cropland classification and forest and pasture use patterns; (c) spatial variables such as Taiwan's fifteen major productive counties, all of which are specified from the first quarter of 2003 to the first quarter of 2015. The study accommodates more than 130 agricultural and forestry commodities and the crop mix data of commodities are specified at the sub-regional level. The availability of total farm labor, cropland, pasture land, forest land and released land is specified at the sub-regional level and eventually mapped to the regional level. The quantity demanded, quantity supplied, elasticity and prices of commodities are also accommodated. Because the import and export of agricultural commodities are important issues in Taiwan, the tariffs of each

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