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The Impact of the Introduction of Hydrogen Energy into the Power Sector on the Economy and Energy Sectors

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Abstract. This study addresses economic and environmental interactions in a dynamic computable general equilibrium (CGE) focusing on the economic effects of the introduction of renewable energy into the Korean energy system. Firstly, demand for electricity is expected to increase due to the introduction of renewable energy into the power sector. Given the introduction of renewable energy in the power sector, demand for fossil fuel decreases, especially demand for coal. Secondly, the mandatory introduction of renewable energy and government subsidies thereof effect a reduction in total demand. In cases in which the renewable energy industry is funded by government, household income will decrease due to increases in taxes, thus reducing aggregate demand. However, our analysis indicates that demand decline eventually eases off with GDP growth. Reductions in production cost are explained by financial support from the government, and GDP growth is expected to come from the increase in investments in renewable energy production coupled to increases in renewable energy output. Additionally, the mandatory introduction of hydrogen energy into the power sector helps to reduce CO2 emissions through the transition from a carbon economy based on fossil energy to a hydrogen economy.

Keywords: Emissions Trading; Regional General Equilibrium Modeling; Economic Welfare

1. Introduction

In December 1993, Korea joined the UNFCCC (United Nations Framework Convention on Climate Change) to international coordinate efforts to tackle global warming, and ratified the Kyoto Protocol in November 2002. Korea has been classified as one of the Parties not included in Annex I, and has no obligation to reduce greenhouse gas emissions during the first commitment period; however, after the first commitment period, the international demand for Koreans' participation in these international efforts by legally binding targets to tackle global warming would be even stronger, since Korea's total levels of emissions of carbon dioxide (CO_2) - one of the main greenhouse gases - have reached 9th place worldwide (no. 1 within OECD members).

In this regard, considering that energy savings and greenhouse gas emission reductions both to be feasible in regard to the national economy's long-term development goals, the Korean government, since 1999, has advocated for a three-phase comprehensive counterplan to cope with the UNFCCC. In 2005, the government entered the third phase of this comprehensive plan.

In 2006, the Korean government announced a "National Vision of a Hydrogen Economy and the Action Plan" to transform Korea from a carbon-intensive economy into a hydrogen-based one. According to the scheme, hydrogen-derived energy would supply more than 15% of final energy demand by 2040, while over

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USD 200 billion would be invested toward the construction of a hydrogen economy (Korea Energy Economics Institute, 2005).

The transition from a carbon economy based on fossil fuel to a hydrogen economy is necessary to ensure energy security and to combat climate change. In cases in which hydrogen is generated from low carbon energy sources, there are the additional advantages of reductions of carbon dioxide emissions. However, the introduction of hydrogen energy is expected to entail substantial costs relative to fossil energy. Thus, in order to pursue the transition to a hydrogen economy while achieving sustainable economic growth, a preliminary study into the establishment of infrastructure for the future hydrogen economy needs to be carried out.

There are two widespread modeling approaches for the quantitative assessment of economic impacts induced by energy policies: bottom-up models[2] of the energy system and top-down models[3] of the broader economy. The two model classes differ principally with regard to the emphasis placed on technological details of the energy system vis-a-vis the comprehensiveness of endogenous market adjustments.

The specific strengths and weaknesses of the bottom-up and top-down approaches explain a broad range of hybrid modeling efforts that combine the technological explicitness of bottom-up models with the economic comprehensiveness of top-down models (see Hourcade, Jaccard, Bataille and Gershi (2006)). Recent hybrid modelling approaches based on the same technique have been previously described by Bahn, Kypreos, B'Nueler and Luethi (1999), Messner and Schrattenholzer (2000), and Bosetti, Carraro, Galeotti, Massetti and Tavoni (2006). In an earlier paper, Bohringer (1998) stressed the difference between bottom-up and top-down with regard to the characterization of technology options and associated input substitution possibilities in production. More recently, Schumacher and Sands (2006) investigated process shifts and changes in the fuel input structure for the steel industry, comparing an aggregate top-down production characterization with a bottom-up description of technologies for iron and steel production. Both papers highlight the importance of "true" technology-based activity analyses in the evaluation of policy-induced structural change at the sectoral level.

In this paper, we evaluate the economic consequences of promoting the increased market penetration of electricity produced from hydrogen energy within Korea. We focus on the policy instruments which are central to the Korean strategy for the promotion of RPS: namely, quota obligation systems.

The remainder of this paper is as follows: Section 2 provides a brief summary of the dynamic CGE model for the promotion of hydrogen energy in electricity production. Section 3 describes the database underlying our numerical analysis and our modeling scenarios. Section 4 presents the main results. Section 6 provides our conclusions.

2. Model Specification

General-equilibrium theory in economics is often quite abstract. A usual introductory formulation consists of a set of markets for goods and factors of production. Agents, which are typically labeled "consumers" and "firms", strive for optimization subject to the constraints they face, such as technologies and budget constraints. These optimizations then lead to excess demand functions for each good and factor. Equilibrium is then obtained by finding a set of prices such that all excess demands are zero.

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[2] Bottom-up energy system models are partial equilibrium representations of the energy sector. They feature a large number of discrete energy technologies to capture substitution of energy carriers on the primary and final energy levels, process substitution, or efficiency improvements. Such models frequently neglect the macroeconomic impact of energy policies. Bottom-up energy system models are typically cast as optimization problems that compute the least-cost combination of energy system activities to meet a given demand for final energy or energy services subject to technical restrictions and energy policy constraints (Rutherford et al., 2008).

[3] Top-down models adopt an economy-wide perspective, taking into account initial market distortions, pecuniary spillovers, and income effects for various economic agents such as households or government. Endogeneity in economic responses to policy shocks typically comes at the expense of specific sectoral or technological details. Conventional top-down models of energy-economy interactions are characterized by a limited representation of the energy system. Energy transformation processes are characterized by smooth production functions which capture local substitution (transformation) possibilities through constant elasticities of substitution (transformation). As a consequence, top-down models usually lack detail on current and future technological options which may be relevant for an appropriate assessment of energy policy proposals. In addition, top-down models may not assure fundamental physical restrictions such as the conservation of matter and energy (Rutherford et al., 2008).

General-equilibrium theory is generally focused on abstract issues, such as proving that a set of equilibrium prices and hence equilibrium itself exists.

3. Data and Scenarios

There are both positive and negative entries in the SAM. A positive entry signifies a receipt (sale) in a particular market; a negative entry signifies an expenditure (purchase) in a particular market. Reading down a production column, we then can observe a complete list of the transactions associated with that activity.

A rectangular SAM is balanced or micro-consistent when the row and column sum to zero. Positive numbers represent the value of commodity flows into the economy (sales or factor supplies), while negative numbers represent the value of commodity flows out of the economy (factor demands or final demands).

In this paper, we use Korean national input-output (IO) data from 2005 (Bank of Korea, 2008) to create a social accounting matrix (SAM) representing transactions of industry, commodity, factor, final payments, and final demands.

We set up bottom-up technology coefficients (cost data) for initially inactive technologies. In our central case simulations, the unit-output of inactive hydrogen technologies is characterized by a technology-specific cost disadvantage vis-à-vis the electricity price in the base year: hydrogen is listed as 30% more costly.

One policy scenario consists of the impact of different introduction of hydrogen energy into electric sector, low (4.8%), base (5.0%), and high (5.2%).

In this paper, we can implement the imposition of green quotas by setting a cumulative quantity constraint on the share of electricity deriving from hydrogen energy. This quantity constraint is associated with a complementary endogenous subsidy on renewable electricity production.

Target groups for this analysis included 2 regions, 6 sectors, and 3 production factors. Fossil fuels are classified as coal, oil, electricity, LNG and hydrogen, as the use of fossil fuel energy is the main reason for environmental pollution, and the degree of pollution depends on each energy source.

Hydrogen scenarios are set by mixing three alternatives from the demand side and three alternatives from the supply side corresponding to the demand side. The demand side alternatives are classified as baseline demand, high demand, and low demand according to hydrogen demand. Under the baseline demand scenario, hydrogen energy will account for a 5% market share in 2031. Hydrogen demand is expected to reach 12.19 million tons in 2050. Under the high demand scenario, the timing of the 5% market share will be moved up, but the hydrogen energy demand in 2050 may be similar to that under the baseline scenario, as the demand is expected to be saturated around 2050. Under the low demand scenario, hydrogen energy will first be introduced in 2018 and will account for 5% market share between 2031 and 2034. The hydrogen demand is expected to reach 11.60 million tons in 2050.

4. Results

Given the introduction of hydrogen energy in the power sector, demand for fossil fuels has decreased. Even though hydrogen energy is currently not economically feasible, subsidies from the government are expected to lead to a reduction in production costs and a transition in the overall energy mix from a fossil fuel-based paradigm to a hydrogen energy-based one.

This study also shows that demand for LNG starts to decrease in 2015 and decreases to 1.10% against the BAU level by 2050. This is because the introduction of hydrogen energy will replace LNG with hydrogen energy.

Petroleum demand is expected to start to decrease in 2006 and will decrease to 3.42% against the BAU level by 2050. We know that these results demonstrate that the introduction of hydrogen energy will influence the petroleum sector more severely than other fuel sectors.

Other industrial sectors will experience increases in output levels. The outputs of other industries are expected to begin to increase in 2005 and increase to 0.02% against the BAU level by 2050.

The mandatory introduction of hydrogen and government subsidies effects a reduction in the total demand. In cases in which the hydrogen energy industry is funded by government, household income will be reduced due to increases in tax, and total demand will be reduced. However, analysis shows that demand decline eventually eases off with GDP growth. Consumption drops below baseline levels over the full time horizon, demonstrating the welfare cost of the transition towards a green power system.

The reduction in production costs is explained by the financial support from the government, and GDP growth is expected to derive from the increase in the investment in hydrogen production coupled to the increase in hydrogen output. Lump-sum subsidies to hydrogen energy result in an increase in overall investment.

The introduction of hydrogen results in an increase in the investment in hydrogen production and the reduction of production cost, and ultimately leads to GDP growth. The result of this analysis differs from other studies in which it was concluded that the introduction of hydrogen energy is expected to hinder economic growth, since its production cost is far higher than the cost of existing fossil fuels. This is because we assume government subsidy of the hydrogen industry. Therefore, the implementation of a subsidy program is critical for the successful transition to a hydrogen economy.

The mandatory introduction of hydrogen energy in the power sector helps reduce CO2 emissions by virtue of the transition from a carbon economy based on fossil energy to a hydrogen economy. Our analysis shows that CO2 emissions begin to decline following the introduction of hydrogen, and decrease to 0.316% against the BAU level by 2050 under the baseline scenario.

5. Conclusions

This research adopts a dynamic computable general equilibrium model using a top-down approach to estimate the economic effects of the introduction of hydrogen into the Korean energy system. The principal results of the model are as follows.

Firstly, with the introduction of hydrogen energy in the power sector, demand for fossil fuels decreases. Even though hydrogen energy is not economically feasible, government subsidies are expected to lead to reductions in production costs and energy transitions from fossil fuels to hydrogen energy.

Secondly, the mandatory introduction of hydrogen and government subsidies have an effect on the decline in the total demand. In cases in which the hydrogen energy industry is funded by government, household income will decrease due to tax increases and total demand will be decreased. However, our analysis demonstrates that demand decline eventually eases off with GDP growth.

Thirdly, the reduction in production cost is explained by the financial support from the government; GDP growth is determined to derive from the increase in the investment in hydrogen production coupled to the increase in hydrogen output.

Fourthly, the mandatory introduction of hydrogen energy in the power sector helps to reduce CO2 emissions via the transition from a carbon economy based on fossil energy to a hydrogen economy.

Fifthly, the introduction of hydrogen leads to increasing investment in hydrogen production and declining production costs, and ultimately results in GDP growth. The results of this analysis differ from other studies which have concluded that the introduction of hydrogen energy should hinder economic growth since its production cost is much higher than the current cost of fossil fuels. This is because in our study we assume that the government subsidizes the hydrogen industry. Therefore, the implementation of the subsidy program is critical for the successful transition to a hydrogen economy.

As anticipated, our analysis demonstrates that the introduction of hydrogen helps reduce CO2 emissions. This means that hydrogen energy needs to come from non-fossil fuel sources in order for greenhouse gases to be effectively reduced. Therefore, it seems necessary that policy supports be strengthened substantially, and that additional studies be conducted into the production of hydrogen energy from renewable sources.

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