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A dynamic general equilibrium analysis on fostering a hydrogen economy in Korea

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ABSTRACT

Hydrogen is anticipated to become one of the major alternative energy technologies for a sustainable energy system. This study analyzes the dynamic economic impacts of building a hydrogen economy in Korea employing a dynamic Computable General Equilibrium (CGE) model. As a frontier technology, hydrogen is featured as having a slow diffusion rate due to option value, positive externality, resistance of old technology, and complementary vintages. Without government intervention, hydrogen-derived energy will supply up to 6.5% of final energy demand by 2040. Simulation outcomes show that as price subsidy rates increase by 10%, 20%, and 30%, hydrogen demand will increase by 9.2%, 15.2%, and 37.7%, respectively, of final energy demand by 2040. The output of the transportation sector will increase significantly, while demands for oil and electricity will decline. Demands for coal and LNG will experience little change. Household consumption will decline because of the increase of income taxes. Overall GDP will increase because of the increase in exports and investments. CO_2 emission will decline for medium and high subsidy rate cases, but increase for low subsidy cases. Ultimately, subsidy policy on hydrogen will not be an effective measure for mitigating CO_2 emission in Korea when considering dynamic general equilibrium effects.

1. Introduction

Recently the Republic of Korea (ROK) has been increasing efforts to develop new and renewable energy (NRE) sources. The NRE embraces hydrogen, fuel cell, and integrated gasification with combined cycle (IGCC) as well as utilizes solar, wind, biomass, hydro, geothermal, waste, and ocean energy, according to a “Promotion Act of NRE Development, Utilization & Deployment” (Ministry of Commerce, Industry, and Energy, 2003). In 2007, total NRE supply reached 5757 thousand TOE,[1] 2.4% of total primary energy demand in the ROK. Among the NRE, conventional energy sources such as waste and hydropower comprise over 91% of total NRE supply (Korea Energy Management Corporation, 2008). However, total energy supply from modern energy sources such as fuel cell, solar, and wind remains less than 2.5% of total NRE supply.

The fundamental impetus for developing the NRE is concern over depletion of fossil fuels as well as the threat of global climate change. Approximately 97% of total energy consumption in Korea is provided through imported energy. Moreover, Korea is the 7th largest petroleum consumer in the world, though total oil demand depends on foreign countries such as Middle East Asia (Korea Energy Economics Institute, 2008). In this context, volatility of fossil fuel prices can seriously undermine the Korean economy. International crude oil prices skyrocketed to over $140 per barrel in 2008. Many petroleum experts argued that world oil supply would prove inadequate for the explosive increase of world oil demand. According to studies on the prediction of long term crude oil prices and oil peak (Rehrl and Friedrich, 2005; Romm, 2004), significant high oil prices beyond 2010 are expected even without there being a structural change in energy demand.

On the other hand, as the 9th CO_2 emitting country in the world, it is expected that Korea should have the responsibility of reducing CO_2, subsequent to the expiration of Kyoto Protocol in 2012. As a non-Annex I country, Korea has been exempted from the responsibility of reducing green house gases (GHGs) during the regime of the Kyoto Protocol (Intergovernmental Panel on Climate Change, 2001). However, the 13th conference of parties (COP) on climate change held in Bali accelerated the obligation to reduce emissions of major carbon emitting countries, including the U.S.A and major non-annex I countries. Hence, the Korean government is eagerly seeking to implement measures to mitigate GHGs emission levels (United Nations Framework Convention on Climate Change, 2008).

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 vision, hydrogen-derived energy would supply over 15% of final energy demand by 2040 while over $200 billion would be invested in the construction of a hydrogen economy (Korea Energy Economics Institute, 2005).

Hydrogen, as an energy carrier, has multiple advantages. Hydrogen generates no pollutants or GHGs when used for fuel cells (Page and

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[1] TOE stands for ton of oil equivalent. 1TOE is converted to 10^7kcal.

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Krumdieck, 2009). Besides, there is great flexibility in the production of hydrogen: it can be manufactured from coal, natural gas, nuclear power, and renewable sources (Blanchette, 2008). Moreover, hydrogen can conserve energy generated from renewable energy sources (Page and Krumdieck, 2009). Finally, hydrogen is one of the most abundant elements in nature, which means that it can provide inexhaustible, secure, and reliable energy to all countries (Blanchette, 2008).

In spite of the benefits, there exist several obstacles in implementing a hydrogen economy. Fossil fuels such as coal or natural gases are currently the dominant sources of hydrogen production but increase GHGs when converted into hydrogen (Blanchette, 2008). Hydrogen may be generated from nuclear power plants; however these will involve huge construction costs as well as conflict on the location of nuclear wastes. Conversion of renewable energy sources is regarded as the most promising method of making hydrogen, but the conversion technology needs much enhancement in terms of efficiency of hydrogen production, installation, and intermittent power availability (Lipman, 2004; Anthrop, 2004). Along with these issues, there are issues of distribution and storage costs as well as of enhancement of the technology for commercialization (Sperling and Ogden, 2004; Romm, 2004).

The positive as well as negative characteristics of hydrogen derived energy have resulted in firms' deferring the decision to invest in this frontier technology. This “slow diffusion” of new technologies may be explained in several ways. First, uncertain and irreversible investment in new technology creates an “option value” of waiting (Farzin et al., 1998). Second, positive externality from imitating the frontier technology developed by an innovative firm creates an incentive to delay earlier investment in technological innovation (Reinganum, 1981). Third, learning-by-using and spill-over effects reduce the costs of existing technologies and make these more competitive than new technologies (Jovanovic and Lach, 1989). Fourth, switching from conventional technologies to new ones reduces expertise and the rents associated with the old technologies. Hence the group associated with the old technologies may endeavor to block the introduction of new technologies (Mokyr, 1990). Finally, it would make more profitable for firms to improve distinct pieces of conventional technology rather than replace the whole one at once, referred to as ‘complementarity among old and new technology’ (Antonelli, 1993; Colombo and Mosconi, 1995).

A fundamental question in this study is whether government's efforts to accelerate slow diffusion of hydrogen technology via a subsidy policy can be justified. Transition from a conventional energy system to a hydrogen-based energy system will require huge investments in the manufacture, distribution, transportation, storage, and conversion of hydrogen. In order to provide financial incentives to firms adopting hydrogen technology, a price subsidy is one of the possible measures in a government supportive policy. Price subsidies on the utilization of hydrogen will improve the price competitiveness of hydrogen relative to fossil fuels. Eventually more firms will adopt hydrogen technology for producing energy. However, distortions occurring from government intervention in the energy market might overwhelm gains from the construction of a hydrogen economy.

The purpose of this study is to evaluate the economic responses and environmental consequences of a price subsidy policy for the dissemination of hydrogen-derived energy production technology in Korea. A dynamic computable general equilibrium (CGE) model for Korea is employed to quantify the dynamic impacts. The model reflects specific features of hydrogen technology as well as general economic interactions among production, intermediate and final consumption, investment, and trade. Major assumptions include a monopolistically competitive (MNC) energy industry, a learning-by-using (LBU) effect in utilizing hydrogen, and a consideration of the projection of an energy mix for manufacturing hydrogen. We simulate how various rates (low, medium, and high) of price subsidy on the production of hydrogen can affect not only the decision of an MNC energy industry with regard to its portfolio of energy sources, the diffusion of hydrogen, and changes in macroeconomic variables but also how they can affect total CO_2 emission levels in the environment.

There are several studies applying CGE models for evaluating economic and environmental impacts of NRE investment (Ignaciuk and Dellink, 2006; Rana, 2003; Kancs, 2002; Moon and Cho, 2003); however, few studies employ CGE models explicitly treating hydrogen-based energy as an alternative energy sector except Jokisch and Mennel (2007). Jokisch and Mennel evaluate the macroeconomic results of developing hydrogen technology within the transport sector of 10 European countries. Applying a dynamic CGE model PACE-T the data of which are taken from the energy system model MARKAL, they found small improvements in the macroeconomic variables in most European countries even if they relied strongly on the assumptions of the penetration rate and technological progress.

More recently, there are several other approaches regarding economic, environmental, or technical appraisals on the diffusion of hydrogen (Dougherty et al., 2009; Page and Krumdieck, 2009; Doll and Wietschel, 2008; Blanchette, 2008). By quantifying the system-level efficiency of hydrogen, Page and Krumdieck (2009) show that hydrogen energy chains provide little or no system-level efficiency improvement over conventionally generated electricity or internal combustion engines. Meanwhile, significant GHGs reductions may be obtained when hydrogen is derived from clean and zero-carbon production pathways, according to Dougherty et al.'s (2009) research. Additionally, Doll and Wietschel (2008) argue that CO_2 emission may be reduced by up to 60% compared to a reference development for selected European countries, when hydrogen is derived from mixed sources, that is, renewable, fossil energy carriers with carbon capture and sequestration, and nuclear. However, without considering interflow of economic agents and opportunity costs of fostering a hydrogen economy, those studies can overestimate positive economic impacts and environmental consequences. Our study is distinguished from extant literature from the point of view of capturing economic interactions that are affected by the introduction of hydrogen through the financial incentive policy.

In the next section, the overall structure of the dynamic CGE model is described. Section 3 presents data, calibration, and scenarios for modeling. Section 4 summarizes relative changes of micro- and macroeconomic variables in response to subsidy policy. The last section discusses major findings on economic as well as environmental aspects of such subsidies and the resulting policy implications.

2. Model specification

A dynamic CGE model is applied to evaluate the economic and environmental impacts of fostering a hydrogen economy in Korea. Sectors are aggregated into energy, transportation, and all other industrial sectors to reflect that hydrogen is used mainly as fuel for fuel cells in the transportation and electricity sectors. Energy sectors are disaggregated into coal, petroleum, town gas, electricity, heat, NRE, and hydrogen. A central feature of the model is the assumption that existence of monopolistic profits is an important impetus for new investment in the development of frontier technology such as hydrogen-derived energy.

We assume that each energy production sector is monopolistically competitive[2] and the vintage of energy production, termed as time period of a specific energy used, is determined by the number of energy production firms in the market. For example, if fixed costs of a specific energy production industry exceed monopolistic profit, the number of firms will contract and vice versa. In each period, energy mix is determined by the production framework drawn up by Dixit and Stiglitz (1977). A vintage model developed by Mulder et al. (2003), based on the framework of Dixit and Stiglitz (1977), assumes

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[2] Most Korean energy production firms such as KEPCO (Korean Electric Power Corporation), KDHC (Korean District Heating Company), and other electricity companies may be regarded as monopolistically competitive in the market.