Extended Abstract for GTAP Conference

"Integrating Top-down and Bottom-up Approaches: An Integrated Model of Energy for a Developing Country

Many developing countries are highly dependent on fossil fuels and are net importers of oil, which makes them particularly vulnerable to large oil price fluctuations. Oil shocks affect economies through the deterioration of both its trade balance account as well as its fiscal position. The higher oil prices leads to higher oil imports and a worsening of the balance of trade account. The problem is compounded by the fact that this lead to higher subsidies and transfers and hence a deteriorating fiscal position of the economy. International organizations such as the World Bank, the regional banks (Inter-American Bank, Asian Bank and African Bank) are promoting the expansion of renewable electricity generation in developing countries to try to reduce the dependency on fossil fuel of developing economies and make them less vulnerable to oil price shocks. Moreover, renewable energy sources are non-pollutant and non-contributors to greenhouse effects and global warming.

Most of the papers that deal with oil dependency and oil price shocks study developed countries (Berndes and Hansson, 2007; Cuñado and Pérez de Gracia, 2003; Jiménez-Rodriguez and Sánchez (2005); Kilian, 2009; Parry and Darmstadter, 2003). The few papers that analyze developing countries, BRICS, China, Nigeria, for example, do it from the perspective of oil exporting countries rather than oil importing countries (Boadstock, et.al. 2012; Olomola, 2006, Ono, 2011). Moreover, the focus has been on the effects of the oil price shocks on the stock markets rather than on macroeconomic variables of the economy. There are also papers that disaggregate the electricity sector, though the emphasis is on environmental policy and goals, and they assume a smooth substitution between different electricity generation technologies (Peters, 2016), or they analyze the change in the electricity matrix from an engineering perspective (Ponce de Leon Barido, et.al. 2015).

Understanding the economy wide effects from oil price shocks and the expansion of renewable technologies is important particularly for developing countries that are net importers of oil. We have chosen Nicaragua, since it is the second poorest country in the Western Hemisphere; and highly dependent on foreign oil. The country has been gradually making the transition from oil to a range of renewable energy sources. However, the effect on the economy or its different sectors has not been analyzed. If Nicaragua reaches its goal of 90% of its generation from renewable sources by 2020 without having to sacrifice its economic growth or suffer from marked increases in electricity prices; it may provide a path forward for other small and fossil fuel importing countries.

To analyze the implications of changes in the electricity matrix on prices and the economy at large, we need to use a top-down model[1] that allow us to know the effects on the economy at large. In our case we have chosen the Mitigation, Adaptation and New Technologies Applied General Equilibrium (MANAGE) model. However, if we want to know the effect of changes in oil prices or LCOE on the electricity matrix, a bottom-up model[2] must be used, in our case we have chosen OSeMOSYS. To be able to understand the effects on the electricity matrix and the economy at large, we need to combine both approaches. A top-down model relies on "smooth aggregate production functions to describe the technology choice in the electricity sector" (Lanz and Rausch, 2011) that cannot take into account the constraints that are present in this sector. The bottom-up models have a "rich technological underpinning" (Helgesen, 2013) but are partial equilibrium models, that only convey information about the specific sector, i.e. electricity sector. By linking both models,[3] we can take into account the particularities present in the electricity sector, and understand the general equilibrium effects that will arise from changes in prices and in the production mix of electricity, and the implications for the rest of the sectors.

MANAGE was tailored to reflect the Nicaraguan economy using the Nicaraguan social accounting matrix (SAM)[4]. The 2010 SAM of Nicaragua was provided by the Central Bank of Nicaragua[5]. Since the SAM provided by the Central Bank provided an ample disaggregation, we use the richness of the data and disaggregated MANAGE as well into 115 activities (ranging from agriculture to public sector, including as well a disaggregated sector for electricity generation[6]). 118 commodities and factors such as capital, labor (self-employed and employed), land, and natural resources. The elasticities of substitution used in the model are based on the best estimates found in the literature and expert advice (Arrow et al, 1961; Balistreri, 2001; Antras, 2004; van der Werf, 2007; Okagawa and Ban, 2008).

[1] Top down models describe the entire economy and allow the substitution between the different factors of production in the economy, to maximize social welfare (Helgesen, 2013).
[2] Bottom up models include detailed descriptions of the "technological aspects of the energy system and how it can develop in the future"; take the demand as exogenous and give us the most cost efficient way to produce electricity (Helgesen, 2013).
[3] We will be linking both models through a hard linkage. Hard linkage is not the only possible way of linking different models. Soft linkage is another possible way to do it; the difference between hard and soft linkage lies in whether the user controls the transfer of information or not (as defined by Wene, 1996). A third approach is through integration, in which one models influence the other, but they are not run independently.
[4] A Social Accounting Matrix is an Input-Output matrix that also includes economic transactions of the economy. The cells show payments from the accounts in the columns to the accounts in the rows.
[5] On a confidential basis.
[6] The disaggregation included: thermal public generation, hydroelectric public generation, thermal private generation, geothermal private generation, hydroelectric private generation, biomass private generation, wind private generation, transmission services, distribution services, refined oil.

To adapt OSeMOSYS to Nicaragua electricity system, we have used information from the MEM as well as the National Center of Energy Dispatch (CNDC for its acronym in Spanish). For the demand generation we have used the hourly historical national electricity demand as well as the generation profile. The wind turbine output comes from historical values as well as projections from the MEM. The average solar irradiation in Nicaragua is 5.21kWh m^{-2} d^{-1} with different irradiation depending on the area of the country. We have also taken into account the seasonality present in Nicaragua, where February to May are the sunniest months. The geothermal and biomass estimates used the information provided from the MEM about the historical information on generation and production (utilization factor, effective capacity and installed capacity). The costs in the objective function and for each electricity generating technology also come from information provided by the MEM. The model uses a discount rate of 5 percent and two modes of operation[7]. The projections made for MANAGE and OSeMOSYS are from 2011-2040.

The models run simultaneously[8], with the demands of the electricity sector coming from the MANAGE model based on exogenous information from the Ministry of Energy and Mines of Nicaragua (MEM). The information from the MEM serves to determine the level of demand that must be satisfied by OSeMOSYS model. OSeMOSYS provides the electricity mix matrix that is most cost efficient, as well as the information about cost of production of each input technology, used by MANAGE to determine the demand for each electricity generating technology and iterate over until a solution is obtained[9],[10].

The main contribution of this paper is to link an energy model with a CGE model so that we can obtain more realistic general equilibrium effects a change in the energy matrix as well as of oil price shocks on an oil-importing developing country, where 50 percent or more of the electricity comes from the conversion of oil into electricity Moreover, it provides estimates of the welfare impacts and distributional effects (that also takes into account the Nicaraguan energy incentives) of changes in the electricity matrix, from a predominately-fossil fuel base generation to renewable electricity generating sources.

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[7] Modes of operation are usually defined “if a technology can use various input or output fuels and can choose the mix of these input or output/fuels. In OSeMOSYS for example, a CHP plant may vary between producing heat in one “mode of operation” and electricity in another. The “capacity” remains constant simply because the same piece of machinery produces both outputs. The modes of operation are indexed by the letter “m””.

[8] One of the possible ways to link the model if we want to preserve a “higher resolution depiction of the economy” (Arndt, et.al, 2015) is to link them via a sequential process or via a recursive dynamic process, avoiding “forward-looking intertemporal dynamics in the CGE”.

[9] Lantz and Raush (2011) uses the decomposition algorithm developed by Bohringer and Rutherford (2009), “which employs an iterative solution procedure to solve top-down and bottom-up model components consistently”.

[10] The other way to integrate both models is to treat each iteration as a movement in time towards an equilibrium, or a “rolling procedure”. Also Arndt et.al 2015 state that by collapsing their different energy plant mix into one composite sector, they were able to “endogenously determine the future levels of electricity demand and supply, especially when applying shocks or policies that change the power plant mix and the prices of electricity.

The scenarios developed in this paper are the following:

- Oil price shocks with pass through
  - In MANAGE versus Integrated model
- Oil price shocks with no pass through
  - In MANAGE versus Integrated model
- Increase in renewable energy
  - In MANAGE versus Integrated model