ELECTRICITY INTERCONNECTION WITH INTERMITTENT RENEWABLES

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Overview

Electricity interconnection has been recognized as a way to mitigate carbon emissions by dispatching more efficient electricity production and accommodating the growing integration of renewables. I analyze the impact of electricity interconnection in the presence of intermittent renewables, such as wind and solar power, on the optimal energy mix and carbon emissions using a two-country model. I find that in the first-best, interconnection decreases investments in renewable capacity and exacerbates carbon emissions if the Pigouvian carbon price is low. Conversely, interconnection increases renewable capacity and reduces carbon emissions for a high carbon price. Moreover, the intermittency of renewables generates an insurance gain from interconnection, which also implies that some renewable capacity is optimally curtailed in some states of nature when the carbon price is high. The curtailment rate and the corresponding carbon emissions increase for more positively correlated intermittency. I calibrate the model using data from the European Union electricity market and simulate the outcome of expanding interconnection between Germany-Poland and France-Spain. I find that given the current level of carbon tax, the interconnection alone may increase carbon emissions.

Methods

This paper builds the work of Ambec and Crampes (2012) and Joskow and Tirole (2000) and constructs a stylized model of electricity trade. Interconnection takes place between two countries (or regions); each can be of the Clean type or the Dirty type. I solve the special case of symmetric countries analytically if they are of the same type. This simplification makes the theoretical results more tractable. In the simulation, I consider the more general cases of asymmetric countries.

On the supply side, electricity can be generated from two technologies: a fully controllable polluting thermal power and a clean but intermittent renewable energy source. The Clean country has both technologies available, whereas the Dirty country has only thermal power. The market is fully competitive for both technologies.

The thermal power has constant unit capacity and fuel costs. Production from fossil energy emits greenhouse gas (GHG) and other pollutants to the atmosphere. There is a global carbon price on each unit of thermal production. For the intermittent renewables, the capacity cost is convex to capture that capacity is installed in the most efficient locations first and subsequently installed in locations with a lower hourly yield. For each country, there are two states of nature with high and low renewables output. The exogenous probabilities of the states capture the degree of intermittency of the renewables. Across countries, the intermittent state can appear with a correlation factor. Electricity interconnection allows bilateral countries to trade electricity up to the transmission capacity.

On the demand side, consumers in each country derive an aggregate gross utility from electricity consumption. The consumers are assumed to have non-state-contingent demand and face constant retail electricity prices. Moreover, rationing is not allowed, i.e. there can be no partial blackouts.

First, I analyze the benchmark case of autarky. Under autarky, each country maximizes its expected social welfare by choosing the optimal level of installed capacity and electricity consumption. Then, I consider electricity interconnection between a Clean and a Dirty country and two Clean countries. With interconnection, the countries jointly maximize their expected social surplus by choosing the levels of installed capacities, state-dependent production levels, and consumption. By comparing the optimal energy mix under autarky and trade, I obtain the key results. Finally, calibrated simulations with data from the European electricity markets are carried out to estimate the scale of the interconnection effect.

Results

The theoretical analysis shows that the effect of interconnection depends on the characteristics of the two trading markets. First, consider interconnection between one Clean and one Dirty country, where the Dirty country has an absolute advantage over thermal production. In this case, expanding interconnection has ambiguous effects on carbon emissions, depending on the level of the Pigouvian carbon price. If the carbon price is low, interconnection exacerbates carbon emissions because of lowered renewable investment and increased electricity consumption. The intuition lies in the fact that transmission is a two-way street. It facilitates not only renewable diffusion when the wind is blowing, but also the dispersion of cheaper thermal production when generation backup is needed. With a low carbon price, interconnection gives the Clean country access to a lower-cost thermal technology, which would decrease its adoption of renewables (composition effect). In addition, the optimal consumption in the Clean country increases with interconnection, because of the cheaper backup thermal energy (scale effect). Both the scale and composition effect push emissions upward. However, with a high carbon price, interconnection expands the market of Clean country renewables, which are now less costly than thermal energy (composition effect). The composition and scale effect take opposite directions, and depending on which effect dominates, emissions can increase or decrease.

Second, if both countries are Clean and have imperfectly correlated renewable energy, then renewable curtailment, i.e., having idle renewable capacity or disposing of renewable generated electricity, may be optimal in some states. Interconnection kicks in as insurance against intermittency when the wind in one country dies and is still blowing in the other country. For the country in which the wind is still blowing to export electricity, they must have a renewable capacity exceeding local demand. This excess supply becomes idle when the wind is blowing in both countries. The renewable curtailment rate and the corresponding level of carbon emissions depend positively on the correlation of occurrence of their windy states. The more positively correlated, the more likely some capacity stays idle and the higher the carbon emissions, all else being equal. Therefore, not allowing for curtailment reduces the capacity that can be installed, undermining any insurance motive of interconnection, and trade will not take place in any state of nature.

To quantify the scale of the effect in the theoretical analysis, I simulate the model with four European countries and relaxed some of the simplifying assumptions in the model. The four countries represent four distinctive energy profiles: Germany has various types of coal and renewables; Poland is predominantly powered by coal; France has over 70% nuclear with gas and wind power; and Spain has a mix of nuclear, thermal, and renewables. Therefore, I use Germany-Poland (DE-PL) and France-Spain (FR-ES) interconnections to represent the Clean-Dirty and Clean-Clean case, respectively. For the FR-ES interconnection, I also simulate FR wind-ES wind and FR wind-ES solar separately, to explore the effect of intermittency correlation. Since the four countries are also geographically connected and have existing transmission lines in use, understanding the impact of existing transmission capacity is important in the representative European Union (EU) context. Simulation results show that achieving the EU's 2030 interconnection target under a carbon price of €45 per ton of CO2 increases annual emission by 1.69% in the DE-PL case, by 1.74% in the FR wind-ES wind case, and reduces emission by 7.18% in the FR wind-ES solar case in comparison with the status quo.

Policy Implications

There are a few policies implications that can be drawn from the results. First, interconnection alone cannot automatically ensure the deepening of renewable penetration and reduced carbon emissions. It needs to be complemented by the other policy instruments carbon taxes or renewable subsidies. Second, the interconnection target should not be set uniformly across countries regardless of the existing energy mix. Interconnection should be first installed between countries that already have significant shares of renewables and subsequently installed between countries that rely more on fossil fuels when the carbon price is higher or the renewable cost is lower. Third, with more existing interconnection capacity, connected countries should coordinate to invest in more negatively correlated renewable technology rather than staying technology-neutral. This would help countries to harness more the potential of the interconnection capacities and jointly reduces carbon emissions.

References

Ambec, S., & Crampes, C. (2012). Electricity provision with intermittent sources of energy. *Resource and Energy Economics*, *34*(3), 319-336.

Antweiler, W. (2016). Cross-border trade in electricity. *Journal of International Economics*, *101*, 42-51.

Antweiler, W., Copeland, B. R., & Taylor, M. S. (2001). Is free trade good for the environment?. *American Economic Review*, *91*(4), 877-908.

Copeland, B. R., & Taylor, M. S. (1994). North-South trade and the environment. *The Quarterly Journal of Economics*, *109*(3), 755-787.

Joskow, P., & Tirole, J. (2000). Transmission rights and market power on electric power networks. *Rand Journal of Economics*, 450–487.