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Capacity constraints, transmission investments, and incentive schemes

Luigi Sereno*, Tilemahos Efthimiadis

European Commission, Joint Research Centre, Dir. C-Energy, Transport, and Climate, Westerduinweg 3, 1755ZG Petten, the Netherlands

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ABSTRACT

We consider firms facing uncertain demand, and study their problem of investing in an electricity line between two neighbouring countries, under capacity constraints, and incentive schemes. We consider three ownership structures: a state-owned transmission company, a merchant transmission investor, and a regulated firm. The firm's problem is to choose the optimal time and size of the interconnector. The government is concerned with the incentive design. We investigate how price caps, capacity targets and merchant investments affect the critical investment thresholds and characterize the government's optimal incentive. We find that price caps speed-up projects' development, while capacity targets reduce under-investments in capacity markets. Finally, we study the effect of investment decisions on the social welfare value.

1. Introduction

Transferring large amounts of electricity over very long distances, through overhead lines or underground/submarine cables, requires high-voltage direct-current transmission systems. Several such projects are currently under development worldwide. For example, in the Unites States there is a plan to build a 4000 MW interconnector to transfer electricity produced by wind from the Oklahoma Panhandle to Tennessee.[1] Recently, Google and other sponsors have been seeking to connect the mid-Atlantic region with a submarine cable bringing offshore wind power to New Jersey, and other states in the region.[2] China has also been developing ultra-high-voltage direct-current projects since 2010. It includes the largest worldwide overhead interconnector under construction, a 3.400 km interconnector linking the coal and wind-rich region of Xinjiang, in the north-west of the country, with the Anhui province in the east part.

In the European Union, the European Commission (Communication COM, 2014 No. 330) set targets to accelerate the construction of key interconnections between national grids, with the goal of strengthening cooperation among Member States, creating a single electricity market, and incorporating the (booming) wind and solar energy sectors. Moreover, in the context of interconnecting global electricity markets, a stronger European role is envisioned in developing relevant strategic partnerships with other countries such as the Unites States and Canada (Communication COM 2015 No. 80).

In light of the above, our paper studies the economic appraisal of electricity interconnectors under different economic and technical constraints. We consider a two-country framework in which generators make production decisions, and consumers demand electricity. In a centralized trading of electricity framework, an independent system operator (ISO) sets nodal prices to maximize the very short-term social welfare. We first study the two countries separately and find the economic dispatch and the nodal prices. Then, we present an interconnected market where the flow on the interconnector is constrained to the capacity of that line, and compute the economic dispatch and the nodal prices.

For the long-run, we study the firm's transmission investment decisions, that is, the timing and sizing of interconnection capacity. We consider three cases: 1) investment decisions made by a state-owned transmission company (that is a joint venture of national transmission companies); 2) investment decisions made by an unregulated private company (that is a pure merchant transmission investor), and 3) investment decisions made by a regulated company (that is a regulated merchant transmission investor). The first approach is used to define the benchmark against which the merchant and the regulatory approaches are compared. The second approach is based on long-term financial transmission rights entitling holders to a stream of revenues, i.e. the difference of nodal prices between the two countries times the capacity of the allocated financial transmission contracts, which are then used to recover investment costs (see Joskow and Tirole, 2000; Hogan, 2002 and Pringles et al., 2015). We assume free-of-charge financial transmission contracts and concentrate on the valuation of interconnector projects that are protected by infinitely-lived types of them.

* Corresponding author.
E-mail addresses: luigi.sereno@ec.europa.eu (L. Sereno), tilemahos.efthimiadis@ec.europa.eu (T. Efthimiadis).

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[2] Kiger. P. J. (2014) New energy projects boost the use of undersea power cables. National Geographic.

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The third approach relies on regulatory mechanisms for transmission companies (see Léautier, 2000; Vogelsang, 2001, and Hogan et al., 2010 among others). Specifically, we consider price cap and capacity target mechanisms as long-term investment incentives for private transmission investors. Our objective is to study how these policies perform against two types of market failures: delays in project implementation and under-investments in capacity markets. The former comes from the uncertainties affecting large infrastructure projects such as interconnectors, which may lead to delays in the initialization and even the completion of investments. The latter emerges since merchant investors restrict the capacity of interconnectors to maximize their congestion rent and to speed-up the recovery of investment costs. In this context, we provide a policy recommendation for energy regulators. We find that price caps speed-up projects' development, while capacity targets reduce under-investments in capacity markets. Hence, if a regulator wants to ensure the timely implementation of strategic interconnections, then a price cap mechanism is preferable to a capacity target, while, if a regulator wants to achieve the maximum capacity level (and reduce under-investment issues), then a capacity target must be used. Our welfare analysis shows that society is better-off when a capacity target is implemented.

The paper is organized as follows. Section 2 provides a literature review. Section 3 characterizes the optimal dispatch of electrical energy, both for independent electricity markets and interconnected markets. Section 4 derives the surplus from interconnecting electricity markets for society. Section 5 presents the long-term decision problem of a state-owned transmission company. We provide closed-form formulas for the optimal time and the optimal capacity of the interconnector. Section 6 presents the investment problem of a merchant transmission investor. We show that allowing merchant investors investing in the interconnector leads to an under-investment problem in capacity markets. Section 7 presents the optimal investment timing and size of a merchant investor regulated by price caps and compare them with those obtained in the state-owned, and the pure merchant cases. We show that price caps speed-up project implementations, but reduce its capacity, exacerbating the under-investment problem in capacity markets. Section 8 presents the investment model of a merchant investor regulated by capacity targets. We show that capacity targets increase the interconnector capacity, but slow down the project implementation. In Section 9 we rank the investment schemes according to the welfare effects using the benefit-to-cost ratio. A numerical application is presented in Section 10. Section 11 concludes the paper. All proofs are in the appendix.

2. Literature review

Our paper is related to the literature on the evaluation of transmission investments using real options (RO) analysis. RO has been a widely used method in decision-making for (large) infrastructure projects, such as interconnectors, as the method is well suited for studying uncertainty affecting grid expansion projects. One of the first contributions is Martzoukos and Teplitz-Sembitzky (1992) who illustrate how standard option valuation techniques can be used to compute the value of the grid expansion under uncertainty about the electricity demand. They show that demand uncertainty creates an incentive to delay the expansion of the grid beyond the date that would be optimal in the absence of uncertainty. Saphores et al. (2004) analyze an investment in a new high-voltage electricity line under regulatory uncertainty. They set up a two-stage investment model where the project must undergo an uncertain environmental impact assessment before being implemented. They find that a decrease in the probability of success in the regulatory approval delays the decision to start the regulatory process, and diminishes the value of the project. Hence, they argue to set limits to the time of permit granting. Moreover, they find that the duration of permits may significantly affect the decision to start the regulatory process and to invest, but has little impact on the value of the project. Hence, they argue to set limit on the time of permit duration. Abadie and Chamorro (2011) show how binomial lattice methods can be used to compute the value of a grid expansion under economic and technical uncertainties. Using a simple two-bus system, they study the potential benefit of grid expansion on the system reliability when the consumer's demand, fuel and emission allowance prices follow stochastic processes. Moreover, their cost minimization problem is subject to physics laws and technical constraints.

RO analysis allows to evaluate programs for the integration of renewable sources into the electricity system. Kucsera and Rammerstorfer (2014) develop a RO model where a private transmission company has to invest in the expansion of network to accommodate the integration of new renewable generation plants, and study the optimal price cap which assure their connection. Dockner et al. (2013) consider a system operator with a given transmission capacity facing the risk of stochastic demand, and study the short-term decision of costly balancing the grid at any time together with the long-term decision of investing into the grid expansion.

The other stream of the literature relevant for our purpose regards the RO analysis of merchant transmission investments. Siddiqui and Gupta (2007) analyze the transmission investment problem by modelling the decision of a firm holding a real option to construct a transmission line. They determine both the optimal investment timing and the line capacity under uncertain congestion rents. Pringles et al. (2015) develop a numerical model to study the evaluation of grid expansion investments considering the option to defer investments at any time, and the uncertainties about the electricity demand and the price of fuels. Their model mostly relies on the merchant line approach where the revenues generated by the transmission project are a function of the difference of locational prices between the electricity nodes of the transmission branch. Pringles et al. (2014) study regulatory incentives for transmission system expansions under the RO approach. They analyze mechanisms that work on the terms and costs of construction licenses, add premiums on cost of capital of the investment projects, guarantee appropriate return levels to investments, and charge maximum transmission price (price caps). Differently from them, we study how the ownership structure of the company affects investment decisions and social welfare value.

Capacity investments have been studied by three more papers. Boyle et al. (2006) provide an application of the RO concept to grid investment analysis where they consider two transmission alternatives, a large grid upgrade with installation of a 400 kW line, and a small upgrade with installation of a 200 kW line. They study the implications of the different transmission capacities on the timing of implementation of the grid expansion. Fleten et al. (2011) consider two investment alternatives, either constructing a 700 MW cable with a subsequent expansion option or constructing a 1400 MW cable, and study how transmission capacity investments affect electricity price differences between Germany and Norway. Finally, Bakke et al. (2016) apply the binomial option pricing model to study investments in transmission capacity under economic and regulation uncertainty. They consider mutually exclusive investment projects, and evaluate the option of choosing between different locations. These papers don't study how different incentive schemes perform against market failures, as we do.

3. The two-country framework and the short-term dispatch

We present a simple two-country model for the dispatch of electricity. We begin by considering a centralized trading of electricity in each country and no electricity interconnection between them, i.e. the countries are “energy islands”. Then, we model the short-term dispatch with an interconnector in place. Table 1 summarizes the main economic players and their operations.

Consumers (or distributors) purchase electricity from generating companies. The independent system operator (ISO) runs the short-term operations and sets nodal pricing, while the transmission company makes long-run capacity investment decisions, but does not set directly