Would renewable damp oscillations in power markets? An experimental analysis

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Extended abstract:

One of the consequences of liberalization of electricity markets has been the emergence of long-term cycles in generation capacity, which constitute a threat for energy security. The periods with low generation capacity can affect the consumers with high prices, shortages and blackout risk, which translates into a decrease in economic competitiveness of the countries. These risks incentivize the investment in new capacity, which, in the absence of proper planning and regulation, can lead to future over-capacity. During over capacity periods electricity price decreases, causing economic losses to energy companies and even bankruptcy.

Cycles in electricity markets has been widely studied in the past three decades, with the aim firstly of understand its complexity, and secondly to recommend and design energy policies to avoid or mitigate their negative effects. Such studies have been developed from different perspectives, such as analysis of empirical evidence, simulation, and experimental economy, as is has been summarized by Arango and Larsen (2011). Some of the main findings are the understanding of the causes of cycles, which are long delays in capacity construction and capacity vintages. After its comprehension, different mechanisms to mitigate cycles, such as forward markets, mothballing, and capacity mechanisms (Álvarez-Uribe et al., 2018; Arango et al., 2013; Lara-Arango et al., 2017), have been designed, tested an implemented in the past decades. However, such studies consider energy markets dominated by one technology with large delays, such as large-scale hydropower.

With most of the countries facing a transition towards cleaner technologies, new uncertainties have arisen in the recent years in the study of energy cycles. Most of the new technologies have relatively short construction periods, compared to large hydropower, as well as a shorter lifetime, and a different cost-structure. In this study, we present an analysis of energy cycles if a new technology is introduced to a market from an experimental study, with the aim to understand what are the potential changes in cycles that may cause the large scale penetration of non-conventional energy technologies.

As a starting point, we used the model that has been previously used to study energy cycles trough experiments. The base model considers a Symmetrical Cournot five-firms market with linear demand, and which firm has one standard technology with constant unit costs (Arango et al., 2013; Lara-Arango et al., 2017). The model has the basic structure shown in Figure 1, with two state variables: (i) the capacity under construction represents the construction delay, it increases with the annual investments and decreases with the construction rate. (ii) the installed capacity represents the plants under production, and decreases with a depreciation rate (capacity vintages). In the model shown in Figure 1, the decision of investing in new capacity depends on the replacement of depreciated plants (depreciation investment), and a desired capacity. Such desired capacity will depend on the perceived price; if the price is high, a firm will want to sell more energy. With two technology alternatives, each firm will face two decisions: how much to invest, and which fraction of each technology. The model assumes that the fractions are proportional to the perceived profitability of each technology.

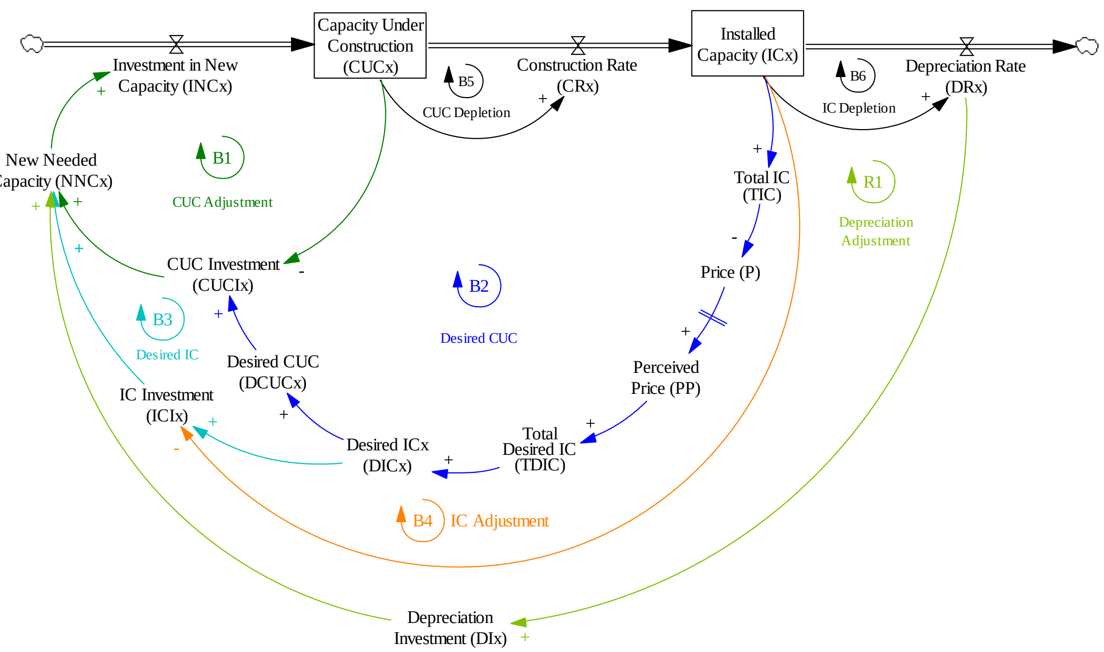

Figure 1 – Stocks and flows diagram for the aggregated market and one technology (Arango-Aramburo et al., 2019).

For the experimental procedure, we opened the loops in Figure 1; for each market we report the capacities and price, and the decision of how much to invest is made by the subjects that participate in the experiment. In order to test the effect of non-conventional technologies such as renewable energy, that have different cost structures and shorter delays compared to traditional technologies, we modified the model to include two generation alternatives and quadratic costs, and express the state variables with a discrete function, in order to keep a record of the age of each investment,

We developed a computer-based experiment with standard conditions (Huck et al., 2004) using the Stella Architect software and based on the dynamic model previously described. Similar to previous work (Arango et al., 2013; Lara-Arango et al., 2017), we considered a symmetrical Cournot market with five players, linear demand and constant marginal costs. Each player represents an electricity firm that must decide the annual investments in new capacity, with the objective of maximizing the profits accumulated during all the experiment.

We selected three treatments the same market conditions, but different cost structures. Treatment 1 (T1) considers one conventional technology with a given construction delay and lifetime, and constant unit costs. Treatment 2 (T2) differs from T1 in the marginal costs function; here, we assume that the total costs have a quadratic function. Treatment 3 (T3) considers that a firm has two technology alternatives to invest in: conventional and non-conventional. These two technologies have different construction delays and lifetimes, and different unit costs function. For all treatments, we assumed that the firms operate at full capacity, with the assumption that 1 unit of installed capacity is equivalent to 1 unit of production. Capacity cannot be negative, and the maximum installed capacity per player is 20 units, to guarantee competition. The experiment considers that the market price depends on the total market capacity (Q), and has the same linear function as (Arango et al., 2013; Lara-Arango et al., 2017), with a maximum of 6 and a minimum of 0. The total market capacity is the sum of all firms' capacities. The parametrization of treatments was selected to guarantee the same equilibria in the three cases.

For the three treatments, we followed the standard experimental economics protocol (see (Cassar and Friedman, 2004)). We designed the experiments in the Stella Architect software, with an online multiplayer platform where individuals can access from a browser. We tested the online platform in several pilots runs with volunteer individuals from the Decision Sciences Research Group. To run the official experiments, we used a computer laboratory at Universidad Nacional de Colombia, adapted with separation panels.

Figure 2 presents the observed prices for five markets in each treatment, compared to the CN and PC equilibria. From a visual inspection, we observed that prices for all treatments have an oscillatory behavior, as demonstrated for liberalized energy markets in previous studies. T2 presents a similar behavior to T1, but with prices oscillating with a smaller amplitude. The introduction of a non-linear cost function changes the financial performance of the firms, but it doesn't change the price behavior, since the model's parameters were selected to reach the same numerical equilibrium. Prices observed in T3 show oscillations with a similar amplitude to T1, but with a higher frequency. This is consistent with the introduction of a second technology in the market with shorter construction and lifetime delays. Thus, the market has a shorter adjustment time for the price.

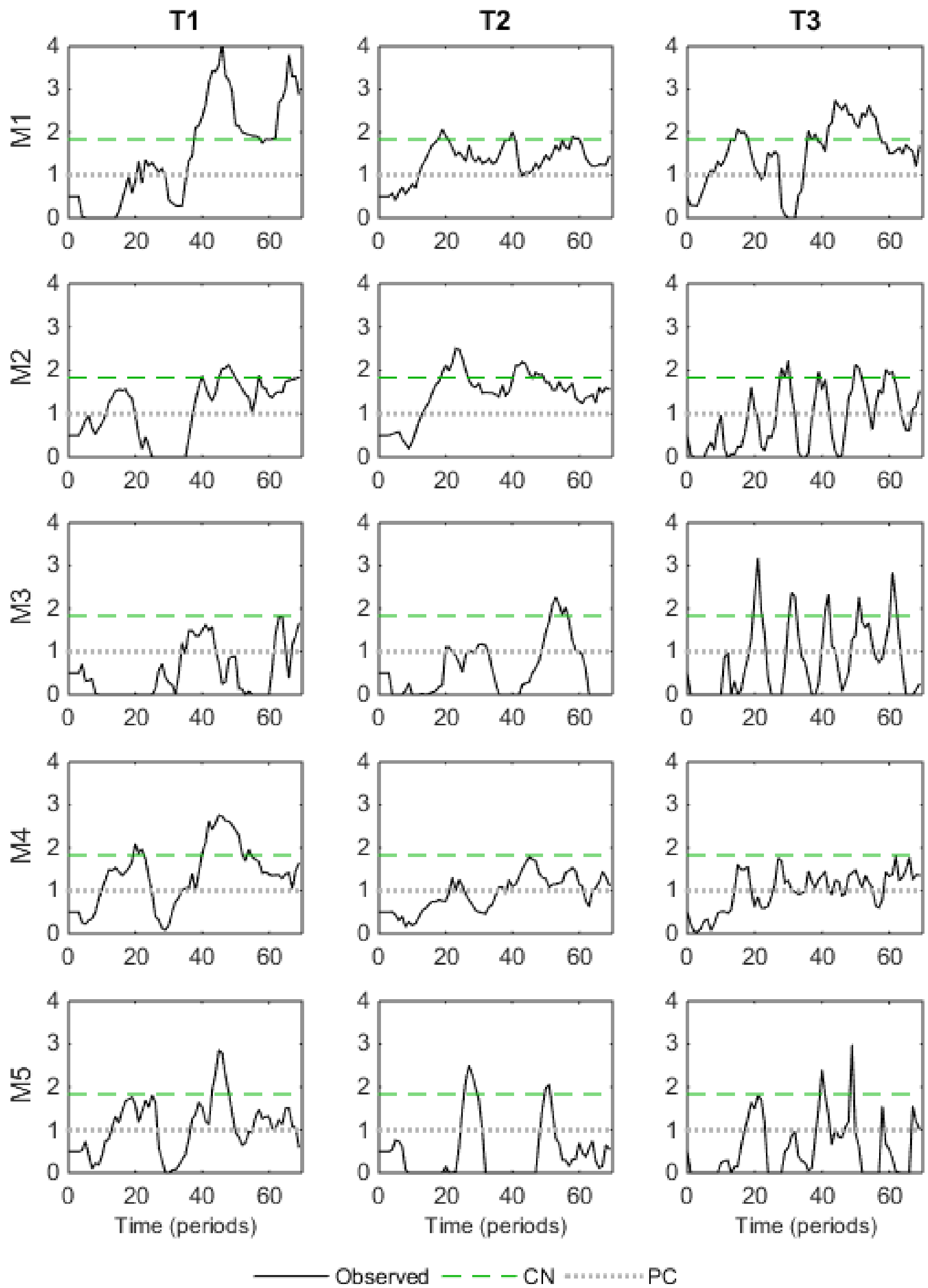

Figure 2 – Experimental results for observed prices in each treatment, compared to Cournot-Nash (CN) and Perfect competition (PC) equilibria.

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