ALGORITHMS IN POWER MARKETS : CAN COLLUSIVE OUTCOMES BE AVOIDED?

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Overview

Electricity markets are currently on the verge of two profound mutations. First, unprecedented breakthroughs in information and communication technologies and renewable generation pave the way for more decentralization. Second, powerful algorithms can optimize consumers' choices on their behalf. It has now become evident that in the near future many energy-consumption decisions will be delegated to these algorithms. Distributed load management being both capital-intensive (batteries), and data-driven, the market is likely to be quite concentrated.

We analyze a setting were a limited number of competitors operate each a fleet of batteries on behalf of a large number of households. We endow these competitors with relatively simple and independent machine learning algorithms who learn how to operate the batteries by themselves. The learning is totally unsupervised, and no information on the structure of the market is provided. No specific instruction is given, only that their objective it to maximize the surplus of their households, based on the sole information of past market prices. We observe that the algorithms quickly learn not only to exert market power, but also to abuse it. Despite the simplicity of the algorithm and the absence of any formal communication between them, they systematically reproduce collusive outcomes. This finding is a generalization of the ones of Calvano et al.(2019) and Waltman and Kaymak (2008), to the much more complex dynamic problem of battery operations. In a move to tame this behavior, we add another player (possibly a regulator), whose objective is to maximize social surplus or minimize supra-competitive profits. Surprisingly, this hypothetical player fails to discipline the collusive behavior in any significant manner. We then propose more innovative strategies.

Our paper urges for regulation of algorithmic decision-making. Using some of the specificities of the electricity sector, we suggest and describe some tools that would allow regulators to ensure consumers enjoy the benefits of algorithms (efficiency) without some of their drawbacks (tendency to reach supra-competitive profits).

Methods

Our paper lies at the intersection between the fields of machine learning, competition economics and power market design. On the former, we implement a highly popular technique for reinforcement learning: Q-learning. This allows our firms to learn by themselves, without any guidance, how to make strategic decisions in the market. Importantly, these algorithms learn simultaneously in the same market – even though they are not even conscious of the presence of a competitor.

This takes us to our second field – competition economics. We monitor and analyse the learning process and the resulting outcome. We observe that the outcome typically generates supra competitive profits and sub-obptimal consumer surplus and welfare. Taking stock of this worrisome observation, we seek how a regulator may keep this behavior in check.

This, we show, is not an easy task as any collusion would be tacit and, therefore, difficult to identify. Our application, the power sector, offers a few alleys worth exploring. We show that endowing a Transmission System Operator or any regulated entity to take an active part in the market when algorithms are in the learning process allows to substantially discipline the market towards more desirable (welfare-maximizing) outcomes. Ensuring the market is truly decentralized also results in more competitive outcomes. We claim that these insights may inspire not only power markets but also other sectors (banking, recommendation algorithms etc.).

Results

Our machine-learning algorithms systematically learn to reach collusive outcomes. We extend current knowledge to the case of a complex and realistic problem: optimal battery charging. Simple, intuitive strategies to tame this behavior fail to solve the issue.

However, two strategies showed promising results. The most direct, but also heavy-handed regulation would be to ensure that algorithms that manage decentralized generation and consumption be themselves decentralized. When each small generators has its own, independent algorithm, they act more competitively. Even though this result is intuitive and in line with economic theory, it had to be checked as counter-intuitive behaviors might emerge from equilibria between algorithms. Another solution may also be to endow a market participant with a disciplining role: During the learning process, this market participant would teach trading algorithms to avoid collusive behaviors.

Conclusions

Decisions are increasingly delegated to algorithms. The electricity sector is no exception, with a large amount of scientific research issued in the past few years praising the merits of digitalization. However, the tremendous opportunities brought about by these new technologies don't come without risks.

In particular, there is overwhelming evidence that many algorithms naturally tend to reach collusive outcomes. We confirm this suspicion with a realistic application to the electricity sector (battery charging). With our deliberate choice of a particularly simple reinforcement learning algorithm, the extent to which we find that algorithms supra-competitive profits can be seen as a lower bound. Despite that, we found that even in sophisticated problems, these simple algorithms tend to converge to welfare-destructive outcomes.

Then, we exploited some of the specificities of power markets to address this issue. We showed that regulators have access to a rather rich set of instruments, which they may use to tame collusive behavior and guide the market towards socially desirable outcomes, instead of the collusive ones.

We acknowledge that the solutions we propose may not be easy to implement in the electricity sector, nor in other sectors. However, we believe that endowing regulators with a better understanding of the behavior of algorithms in their learning phase, may be the first step to finding the adequate regulatory tools to prevent socially undesirable outcomes. Future research can address the implications of more sophisticated algorithms such as neural networks.

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