THE ROLE AND IMPLICATIONS OF ENERGY STORAGE: AN ECONOMIC PERSPECTIVE

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Overview

Due to increasing concerns over climate change, a higher share of energy generated from renewable sources of energy is high on the policy agenda. As renewable sources of energy are inherently variable and uncertain, larger shares of RE generation that are largely policy driven can cause serious vulnerabilities in meeting energy demand and therefore make renewables unreliable base-load contributors. One way of smoothing the operation of existing grids is through the steady use of fossil fuel power plants. These units, however, are expensive to run and add carbon to the air. Grid's flexibility can also be enhanced and enable greater use of renewable energy through demand flexibility, i.e., introducing market or other mechanisms to allow the load to respond to price variations. One other way to enhance the reliability of the grid is energy storage. Energy storage technologies absorb energy and store it for a period of time before releasing it to supply energy or power services. In simple terms, they set aside energy and supply it when renewable energy is not adequate and it is expensive to produce thermal energy.

In the presence of intermittent renewable energy, it then follows that unless some energy is stored there is the danger that consumers face expensive thermal energy during peak times when electricity is likely to be perceived as a necessity. The uncertain supply of RE and the possibility of being exposed to high electricity prices coming from high thermal energy production costs, can indeed lead to an extra demand for energy storage. In addition to enhancing the grids' flexibility, energy storage can serve for an accompanying purpose and allow agents to store energy on the grounds of precautionary motives. For example, prudent agents may want to store more energy and allow for some extra reserve capacity in the presence of intermittent renewable energy. In addition, although the peaker plants can meet the residual load, that fact that this may be very costly when renewable energy is low, and therefore can expose consumers to face with high energy prices, can also encourage the economy to store more energy. In this regard, the precautionary motive is to avoid high thermal energy production costs and enable a smoother operation of the thermal systems. We call this motivation frugality.

In this paper we are mainly interested in explaining to what extent prudence and frugality can spur precautionary energy storage. In doing this we first look at a benevolent planner problem and find out how in the presence of a convex marginal utility (prudence) and a convex marginal cost (frugality) storage decisions are influenced. In doing this we assume different levels of RE penetration to the grid. This is crucial because the scale to which RE penetrates to the system influences the optimal operation of thermal systems. In turn, this affects precautionary energy storage. We then carry our findings to competitive markets and discuss how current energy price and the use of the energy systems are influenced by prudence, frugality, the degree of intermittency and price elasticities.

Methods

Optimization under uncertainty in a two-period model of energy generation and energy storage.

Results

We show that uncertain RE generation delivers a precautionary motive for energy storage when argents are prudent. Considering rather costly thermal energy generation for low levels of RE, frugality suggests an additional motive for energy savings. Thus, having some stored energy can alleviate the exposure to high thermal energy generation costs, stabilize energy price and consumption. Frugality can have a significant impact on energy storage decisions in economies with small scale RE penetration. For large scale RE penetration, this effect diminishes. We carry our findings to competitive markets and show that prudence and frugality can exert an upward pressure on energy prices through higher demand for energy storage. On the contrary, higher price elasticities of demand and supply reduce the influence of the precautionary motives. The degree of intermittency boosts energy storage but to varying degrees. Regarding prudence (frugality), this depends on the ratio of standard deviation in RE to mean level energy consumption (mean level thermal energy generation). The higher these ratios are, the more significant are the effects of intermittency on energy storage.

Conclusions

In the presence of intermittent renewable energy and varying energy demand, energy storage can be a key to bridge the gap between energy supply and demand. Even though energy storage is addressed in many studies in the literature, the extent to which precautionary motives can spur energy storage is not well known. Our paper attempts to fill this gap and shows how characteristics of agents and energy generation technologies can spur precautionary energy storage.

For economies with small scales of RE penetration, we show that there are two different precautionary motives that can spur energy storage. One is prudence, which, in technical terms, is equal to a convex marginal utility. The second motive is frugality, which is observable when the thermal energy industry cost structure can be characterized by a convex marginal cost function.

Our analysis shows that for economies with small scale RE penetration, prudence and frugality cause precautionary energy storage to varying degrees. Even in the absence of prudence, frugality can still allow for precautionary storage. With higher levels of RE generation, the impact of frugality diminishes, but does not vanish unless thermal energy systems become obsolete. Carrying the social planner's results to competitive markets allows us to see in what ways prudence and frugality can affect energy prices. When prudence or frugality are present, then there is precautionary storage and the extra amount of energy storage augments the current energy price. We also show that when the economy can be characterized as prudent and frugal, the degree of intermittency can boost energy storage to varying degrees. Considering prudence, this would depend to the ratio of the standard deviation in RE to the energy consumption that corresponds to the mean-level RE generation. If this share is high, then the degree of intermittency can significantly cause precautionary energy storage and drive up the current energy price. On the contrary, if this share is small, i.e., the deviations in renewable energy constitutes a small share, then intermittency becomes less of a concern and result in a relatively lower level of energy storage and current energy price. Regarding frugality, what matters is the ratio of standard deviation of RE to thermal energy generation at the mean-level RE generation. If this share is high, then the degree of intermittency can also significantly affect the current energy price in the presence of frugality.

We also see that higher price elasticity of demand and supply diminishes the effect of prudence and frugality, respectively. I.e, when consumers are more reactive to changes in the energy price, then consumption adjustment becomes a better substitute for energy storage. Similarly, when energy supply is more price elastic, then changes in thermal energy generation becomes a better substitute for storing energy. Both demand and supply sides effects, i.e., the effects coming from prudence and frugality, respectively, will be weighted differently by the endogenously determined weights. For larger scales of RE penetration, supply side effects will tend to have less influence on precautionary energy storage.