The Texas blackouts earlier this week have reminded us once again of the vital importance of electricity as part of the basic infrastructure of everyday life and the terrible consequences that ensue when the grid fails. Recent reports indicate that dozens of people have died as a result of the extreme weather and blackouts and many Texas residents continue to struggle with a lack of basic services. As Dan pointed out in his recent post and has been widely reported in the media, the rush to blame wind energy and all things green for the blackouts has been thoroughly debunked by the facts. The plain truth of the matter is that all generation resources in Texas were affected by the extreme winter weather. And because Texas is especially dependent on natural gas and because of the tight coupling of the gas supply system and the electricity system, compounding failures in those systems meant that Texas lost substantial thermal generation capacity just when it needed it most.

As much as renewables advocates might want to suggest, however, this was not exactly a victory for wind and solar. The argument that more renewables on the Texas system would have somehow made things better does not hold water. The whole system failed and it will require weeks if not months before we fully understand how this all happened and how to avoid these kinds of events going forward.

More importantly, as we enter a new more expansive phase in the age of electricity—with a push to electrify transportation, buildings, and other sectors of the economy as part of a broader decarbonization effort—our overall dependence on the electric power system (and our corresponding vulnerability to grid disruptions and failures) will ramp up considerably. More rolling blackouts and grid disruptions are not going to make the "electrify everything" pitch any easier.

Reliability and resilience will surely be back on the agenda for power sector reform at both state and federal levels, as stakeholders from all sides seek to define what this means and argue for their preferred resource mix and grid architectures.

Not surprisingly, all of this has also spilled over into the culture wars with pundits and politicians rushing to point fingers and cast blame. Green versus brown; clean versus dirty; California versus Texas; Everyone versus Ted Cruz.

But once we get past the media frenzy, the seriousness of these sorts of events calls for an informed and deliberate conversation about how to manage systems with increasing renewables and natural gas in the face of accelerating climate disruption. To that end, a few observations are worth keeping in mind. First, the heat wave in California this summer and the arctic freeze in Texas this week were, by historical norms, truly extreme events far outside of the bounds of what these systems were designed for and far beyond what

planners had anticipated. To illustrate, earlier this week, parts of southern Texas experienced colder temperatures than parts of Alaska . . . in February! Have you been to Alaska in February?

Second, both of these crises stem in part from the embrace of markets and the specific ways of price making and compensation at the center of the organized electricity markets. Put another way, these episodes stem in part from the ongoing challenges of market governance in electricity markets. California and Texas pioneered electricity deregulation in the 1990s and early 2000s and although California pulled back partially after the western energy crisis of 2000-01, Texas has gone all in. In many ways, Texas has adopted the purest version of electricity markets, relying almost entirely on the day-ahead and real-time electricity auctions (an energy-only market design) to compensate merchant generators and encourage new investment. Because of the uniform clearing price design that all electricity markets have adopted in the U.S. (a design that pays all generators the clearing price established by the last unit of generation needed to meet demand) and by raising the price cap in those markets to $9000 MWh (some nine times higher than price caps in other markets), the ERCOT markets rely on the prospect of massive inframarginal rents during peak periods (such as the recent storms) when price caps are reached to encourage new investments in low cost generation. As a fully restructured state (a state with both retail and wholesale competition), Texas has so far decided against creating the kind of forward capacity market mechanism that other market operators in the eastern part of the U.S. (PJM, New England ISO, and New York ISO) have adopted to provide additional revenues to generators to encourage them to make investments in new generation. The recent events in Texas will surely renew calls for some sort of capacity market mechanism in Texas (a perennial topic in the legislature that often heats up during the period of peak summer demand). But the existing capacity markets, as Dan pointed out in his post, have their own problems and in many ways look like bad cost of service. One key takeaway from the Texas experience is that an overreliance on the prospect of huge profits for a few days of the year as a way to stimulate investment in sufficient long-term generation capacity may be problematic in a climate-changed world where the grid will be subject to extreme weather events far outside historical norms. Another related takeaway is that generators have very limited incentives in this system to invest in weatherization and redundant capacity, which is why the Texas Governor is now calling for new legislation to require such investments. Finally, the Texas system is heavily reliant upon natural gas and renewables (mainly wind) in large part because of these resources are the cheapest sources of power (and thus benefit the most under the Texas market design). As the current crisis has made clear, there are vulnerabilities associated with both of these resources. Wind is intermittent and it can clearly be affected by extreme weather. Natural gas generation is a just-in-time system that

depends upon a tight coupling with the natural gas supply system (production, gathering, and pipeline transport). When cold weather or some other disruption curtails the gas supply system, natural gas generators don't have fuel to burn. As noted, sorting all of this out will take time. And much of it will likely get swept up in the ongoing debates about the future of fossil hydrocarbons in the electricity mix. Battery storage may have an important role to play and Texas's existing nuclear plants will likely get renewed attention. In all of this, we can expect to see more planning and government mandates (yes, even in Texas!) to ensure that the delicate markets Texas relies upon to supply electricity to millions of people will not fail so spectacularly again.

Like Texas, California also relies on day-ahead and real-time electricity auctions to balance supply and demand. These markets are managed by the California Independent System Operator (CAISO), a FERC regulated public utility. But California is not a fully restructured state like Texas. It still has large investor-owned utilities (IOUs) like Southern California Edison and PG&E that serve retail customers through a regulated monopoly franchise arrangement. In effect, California has a hybrid model of electricity regulation—competitive wholesale markets combined with regulated retail service.

California also does not have a capacity market, but for different reasons than Texas. In fact, California takes a very different approach to future capacity than Texas, relying on a Resource Adequacy framework and a two-year integrated resource planning exercise to provide guidance and impose obligations for resource procurement, infrastructure investment, and reliability on load serving entities in the state. This commitment to long-term planning, which is common practice in traditional cost-of-service states, could be viewed as one of the advantages of the hybrid model that is not available in the fully restructured model.

So what happened in August and why didn't the planners plan appropriately for such an event?

The root cause analysis of the California blackouts released in January identified three main causes of the August blackouts: (1) extreme weather far outside of the anticipated scenarios; (2) inadequate planning and a failure to keep up with resource adequacy requirements in the midst of substantial growth in renewables; and (3) certain market practices (specifically, the use of convergence bidding) that masked the true state of supply and demand in the crucial day-ahead energy market.

The first cause is easy to understand: these types of extreme weather events are the new normal and we need to build that into our governance of the electric power sector. The

second point is also relatively straightforward: grid managers and regulators failed to do their jobs and need to be more vigilant and more thorough in their planning exercises going forward, including, of course, planning for extreme weather events. The third point is more obscure, but important to understand. Convergence bidding also known as virtual bidding allows financial institutions and others to buy or sell "virtual" electricity in the day-ahead market and then close out those trades with the opposite transaction in the real-time market. These are financial trades, and no physical electricity is ever delivered as a result of these transactions. The theory behind virtual bidding is that the arbitrage opportunity it represents will improve liquidity in the markets and facilitate convergence between the prices in the day-ahead and real-time markets; that is, the additional trading will "arb out" the price differences between the two markets. But all of that assumes, of course, that these markets are nested—that they operate in actual fact as a multi-settlement market. In many cases, this may be a reasonable assumption, and there is empirical evidence that virtual bidding has facilitated convergence and improved efficiency. In some cases, however, virtual bidding has been used to exploit differences in the rules, models, and algorithms underlying these markets resulting in several high-profile manipulation cases. As a high-level RTO executive recently testified in Congress: "Trading this price inefficiency does not eliminate the inefficiency, it merely profits from it." (For a broader discussion of this in the context of electricity market design, see this recent Article.) The problem with convergence bidding during the August blackouts was that the volume and direction of virtual bids in the day ahead market (mainly supply bids) masked the very tight supply-demand conditions in the markets. In effect, these purely financial bids to supply electricity in the day-ahead market (with no actual electricity behind them) made it look like there was more supply in the day-ahead market than there actually was. The CAISO then allowed for more power exports than it should have, which exacerbated the crisis. Once CAISO recognized the problem, it quickly moved to suspend convergence bidding for the duration of the event. While it will take more time to truly understand all of this in the context of the recent blackouts, including why certain traders took the positions that they did, this does raise important questions about the overall complexity of these markets and the wisdom of allowing financial institutions to participate via purely financial instruments in the actual physical markets for electricity.

In the end, the California and Texas blackouts remind us that an electricity grid operates as one big machine that must perfectly balance supply and demand in real time, all the time. The challenges of imposing market structures on this machine are immense, as we have learned repeatedly over the years, and will surely increase as the climate emergency accelerates. But whatever market design we choose, it is clear that the visible hand of government and the much maligned exercise of planning will need to be deployed with skill

and care to manage these markets and to ensure that the ongoing effort to decarbonize the power sector proceeds in a manner that continues to provide reliable electricity to all Americans.