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The impact of cheap natural gas on marginal emissions from electricity generation and implications for energy policy

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ABSTRACT

We use quasi-experimental variation due to the introduction of fracking to estimate the short-run impact of a decrease in natural gas prices on marginal air pollution emissions from electricity producers. We find that cheap natural gas has shuffled the marginal fuel in different ways in different regions, changing the marginal emissions profile. The impact of cheap natural gas varies across U.S. regions as a function of the existing stock of electricity generation. We demonstrate the impact of these changes on the environmental benefits of energy policy by simulating the installation of wind and solar generating capacity in different regions around the U.S. We construct an hourly data set of potential renewable generation for both wind and solar power and combine that with our estimated marginal emissions. CO_2 emissions offset by wind generation are around 6% lower on average, and emissions offset by solar generation are essentially flat, although the average hides significant variation across regions.

Introduction

Fossil fuels account for roughly 83% of U.S. energy production despite policies aimed at increasing the share of energy produced by renewables.[1] A growing body of work evaluates emissions associated with the residential, commercial and transportation sectors (Jacobsen et al., 2012; Chong, 2012; Bento et al., 2013; Kahn et al., 2014 and Allcott et al. (2014)), but electricity production both consumes the most energy and produces the most pollution of any sector in the U.S. economy.[2] Further, much of the emissions from other sectors stem from their demand for electricity. Due to its reliance on coal, natural gas and oil, the electricity sector remains the single most important source of greenhouse gasses along with many other types of pollution.

Recently, there has been a dramatic shift away from coal-fired electricity generation toward natural gas-fired generation due to the widespread adoption of hydraulic fracturing and horizontal drilling in natural gas extraction known as “fracking.”[3] EIA, 2012 reports that natural gas extracted in this way from shale deposits accounts for over a third of all natural gas produced in 2012, up from less than two percent in 2000. Total production of natural gas also increased by 25%

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[1] As of January 2014. See Energy Information Administration data at: http://www.eia.gov/totalenergy/data/browser/xls.cfm.
[2] See http://www.eia.gov/totalenergy/data/browser/xls.cfm?tbl=T02.01&freq=m.
[3] The academic literature is beginning to evaluate the direct environmental impacts of fracking: Olmstead et al. (2013) and Osborn et al. (2011) estimate the water quality impacts of fracking and Muehlenbachs et al. (2012) estimates the hedonic impacts on well-proximate housing prices.

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over the same time frame with the increase coming entirely from shale gas extraction. This increase in production has been associated with a large decrease in market prices. Natural gas spot and futures prices peaked above $14/MMbtu in late 2005 with continued high prices through 2008 when prices began to fall rapidly as the number of fracking wells increased dramatically. By 2010 the price of natural gas had fallen below $5.00/MMbtu, where it has remained.[4] This change in price was not predicted in commodities markets: in 2008 the futures market for natural gas prices was significantly higher than realized spot market prices. McKinsey, a global management consultancy, has suggested that the fracking boom made "a significant shift in the way we think about energy security, and the way we think about the impact of energy prices on our economy."[5] The Financial Times newspaper claims that fracking" …has changed the world and nothing will ever be the same again".[6] It is increasingly clear that fracking has transformed energy market in the U.S.

In this paper, we identify how marginal emissions rates in the electricity sector have been affected by the unanticipated price change in natural gas due to fracking.[7] To do so, we construct a large and unique data set of hourly electricity generation and pollution emissions data from the U.S. Environmental Protection Agency (E.P.A.) to estimate marginal pollution emissions from electricity production in the U.S. We use the unanticipated change in natural gas prices to identify changes in the marginal emission profile focusing on changes in the composition of fossil fuel electricity generators over time. We estimate the effect on marginal emissions due to the well-known need to account for within and across day variation in emissions rates to evaluate the change in emissions due to electricity sector policies (Holland and Mansur, 2008; Cullen, 2013; Kaffine et al., 2013; Graff-Zivin et al., 2014; Carson and Novan, 2013; Novan (2015)). We provide evidence that the natural gas price decrease was unanticipated by the markets, and therefore take our estimates for the effect of the natural gas price decrease on marginal emissions to be causal.[8]

We use a semi-parametric econometric model with a large number of fixed effects to estimate marginal CO_2 emissions for eight regions throughout the U.S. Our empirical approach borrows from Holland and Mansur (2008) and Graff-Zivin et al. (2014) which use broadly similar identification techniques in other contexts to identify marginal emissions given a set of input prices. We study the time period between 2006 to 2011 in our analysis for two important reasons. First, 2006-2011 saw major exogenous changes in the price of natural gas from the perspective of the electricity generators due to the emergence of fracking. Second, we are primarily interested in the intensive margin response of electricity generators for our policy experiment, which we motivate and discuss below. The 2006-2011 time period is short enough to preclude any significant increase in natural gas generation capacity due to the price change in natural gas. We provide evidence that the decrease in natural gas prices did not spur a large increase in natural gas capacity before the end of 2011.[9] As a result, we are able to isolate the causal effect of short run price fluctuations insofar as it affects the dispatch of extant generation capacity.

We estimate the marginal emissions rate of fossil fuel generators across the country. These rates reflect the additional CO2 emissions associated with a 1MW increase in fossil fuel generation. Renewable generation will offset the highest cost fossil fuel generators. Inexpensive natural gas is likely to change which generators are the most expensive, and thus "at the margin", in a particular hour of the day. For example, natural gas generators that were the most expensive generators in peak hours during the high natural gas price era may be replaced on the margin by coal units after the fall in natural gas prices. These changes in the marginal generator will in turn affect the environmental benefits of renewable generation.

Our estimated marginal emissions vary dramatically across hours of the day, months of the year and regions of the U.S. This variation has been documented in the existing literature. We choose to focus on the change in marginal emissions as a function of the relative input prices for coal and natural gas. In several regions the pattern of marginal emissions across the day switched dramatically due to changes in the dispatch order of electricity generators driven by natural gas prices. We decompose the marginal fuel profile to show that observed changes are due to changes in the marginal fuel over different hours of the day in the low natural gas price environment.

To demonstrate the importance of shifting marginal emissions rates on energy policy we simulate the environmental benefits of adding a small amount of renewable energy to the grid across natural gas price levels. We develop generation supply curves for wind and solar power across hours of the day, months of the year and U.S. regions. First we identify the sites in each region with the highest renewable generation potential for solar and wind generation. We then collect high frequency data on potential generation at those sites from publicly available data sources. This approach generates potential supply curves for renewable generation by source. As shown in Callaway et al. (2015), there is significant variation in potential renewable generation across hours of the day, months of the year and regions of the U.S., highlighting the importance of evaluating the impacts of renewable policy using marginal emissions rates estimated by region.

We combine the estimated marginal emissions rates and potential renewable generation levels to simulate the impact of

[4] Seasonal spikes in price have occasionally led to higher gas prices, particularly in the northeast and upper Midwest, but these high prices have not been sustained.

[5] McKinsey Insights and Publications interview with McKinsey partner Scott Nyquist. Available at http://www.mckinsey.com/insights/economic_studies/the_us_growth_opportunity_in_shale_oil_and_gas.

[6] In a April 24, 2015 article by Ed Crooks entitled "The US Shale Revolution" available at https://www.ft.com/content/2ded7416-e930-11e4-a71a-00144feab7de.

[7] Hausman and Kellogg (2015) focus on the market impacts of fracking. In this paper we study the impacts of fracking on marginal emissions which then affect the non-market implications of fracking.

[8] Increasing prevalence of renewables on the electricity grid and changes in environmental regulation may present challenges to identification. We examine those issues in more detail below.

[9] Expanding the sample to 2005-2012 does not change the qualitative results.