Climate Change, Directed Innovation, and Energy Transition: The Long-run Consequences of the Shale Gas Revolution

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Technological progress in shale gas extraction (specifically the combination of hydraulic fracturing and horizontal drilling) has led to a boom in the natural gas industry in the United States. Shale gas production in the United States increased more than threefold between January 2005 and January 2010, and it has increased close to 5 times more from January 2010 to December 2018. This shale gas boom has revolutionized energy production in the United States. Natural gas started displacing coal at a much faster rate from 2009 so that today natural gas is more important than coal in electricity production. Given that natural gas emits 40-50 percent less carbon per British thermal unit (Btu) of energy than coal, the carbon emission intensity of the electricity sector has declined by around a quarter in a few years. In fact, CO_2 emissions from the electricity sector peaked in 2007 and have kept declining since.

Interestingly, at the time of the shale gas boom, innovation in clean technologies in electricity has collapsed. Figure 1 shows that patenting in renewables or more generally in green energy (which includes renewables, biofuels and nuclear) has collapsed with the shale gas boom, both as a share of total patents and as a ratio relative to patents in fossil fuel electricity generation. For instance, patenting in renewables in the US has gone from representing 0.4% of total patents in 2009 to close to 0.1% in 2015. If the shale gas boom reduced emissions in the short-run at the cost of displacing innovation toward truly green technologies, then its overall effect on emissions and climate change is much less clear.

This paper investigates the short- and long-term effects of a shale gas boom in an economy with directed technical change where energy can be produced with coal, natural gas, or a clean source. In the first part of the paper we develop a simple framework to highlight the key trade-offs involved in allowing for improvements in the intermediate source of energy (specifically, in the extraction technology of natural gas). The final good is produced with an intermediate input and with energy. Energy is itself produced using coal, and/or natural gas, and/or a green source of energy (such as wind and solar power). Fossil fuel energy is produced using a combination of a resource - coal or natural gas - and an energy input (think of a power plant). The green energy is produced using only the intermediate input (representing wind mills, solar panels, etc.). Fossil resource use in energy production in turn generates pollution, with a higher pollution intensity for coal than for gas.

The model delivers the following insights. In the short run - given the current state of technology - there are two effects of a shale gas boom: a substitution effect and a scale effect. First a shale gas boom helps substitute natural gas energy for both coal energy (this reduces emission) and green energy (this increases emission). The overall substitution effect leads to a reduction in aggregate pollution when coal use is sufficiently more polluting than natural gas use. Second a shale gas boom makes overall energy production cheaper which leads to an increase in overall energy consumption and therefore to an increase in aggregate pollution, ceteris paribus. Overall, in the short-run a shale gas boom will reduce pollution when the substitution effect is sufficiently negative and large compared to the scale effect. This in turn occurs when coal is sufficiently more polluting than natural gas at the margin.

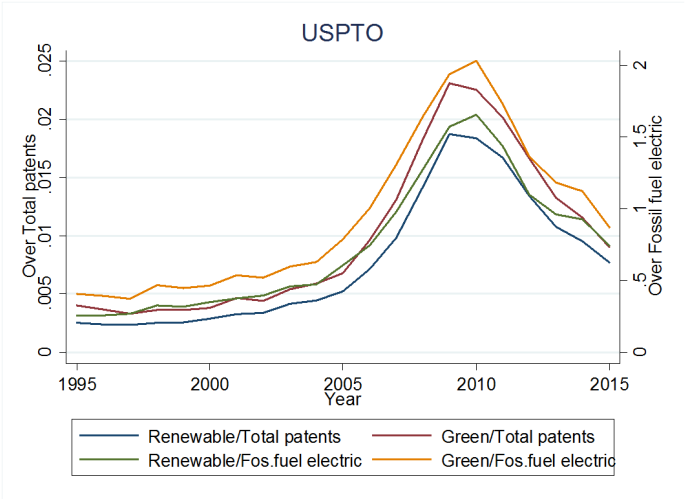


Figure 1: The collapse of clean innovation in electricity

In the long run, a shale gas boom tends to postpone the switch toward green innovation. In fact, we provide sufficient conditions under which a shale gas boom results in the economy getting trapped in fossil fuels, which in turn results in a permanent increase in aggregate emissions whereas in the absence of the shale gas boom emissions would have converged to zero in the long run.

The theoretical analysis demonstrates the potential of an unmanaged shale boom to increase carbon dioxide emissions significantly in the long run. In order to gauge both the potential magnitudes and policy implications of these effects, we move to a quantitative analysis, which proceeds in three parts. We first calibrate an extended version of the static model to the electricity sector in the United States. We use data on electricity production and costs according to the energy source (coal, gas and the different green energies), aggregate data on output, capital, employment, etc., and estimates from the literature on the elasticity of substitution across fuels in order to estimate the initial technology levels. The benchmark results sugest that, for the United States, a reduction in the price of natural gas (akin to the "shale gas revolution") initially led to a decrease in CO_2 emissions (i.e. the intermediate technology has a positive environmental effect in the short-run). Second, we calibrate the dynamics of the model, setting innovation parameters to match our empirical estimates of the decline in the green innovation share observed in the aftermath of the shale boom. Simulating the economy forward, we find that an unmanaged shale gas revolution can lead to substantial increases in carbon emissions and climate damages in the medium- and long-run. Finally, we set up a social planner's problem to consider the implications of the shale boom for climate policy design. In the benchmark scenario, optimal management of the shale boom requires both increases in carbon taxes and higher subsidies for clean energy research.