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

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Extended Abstract

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. As shown in Figure 1, 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. Figure 2.A shows that 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. Panel.B shows the effect of the shale gas boom on CO_2 emissions in the electricity sector. Natural gas causes much less emissions than coal, as a result the CO_2 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.[1]

We document a new fact: at the time of the shale gas boom, innovation in clean technologies in electricity has collapsed. Figure 3 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 asks the following questions: Was the shale gas revolution a boom or a bane for climate change? More generally, should a climate strategy involve the development of bridge technologies such as natural gas, which pollutes but can displace more polluting technologies? Or should it avoid it because of the negative effects of such a policy on truly green innovations? This paper attempts to answer these question by developing a quantitative directed technical change model.

More specifically, in the first part of the paper we develop a simple framework to highlight the key trade-offs involved in allowing for improvement in the intermediate source of energy (which we refer to as 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

[1] All data here are taken from the EIA. The pattern of Figure 2.B also applies for the entire economy.

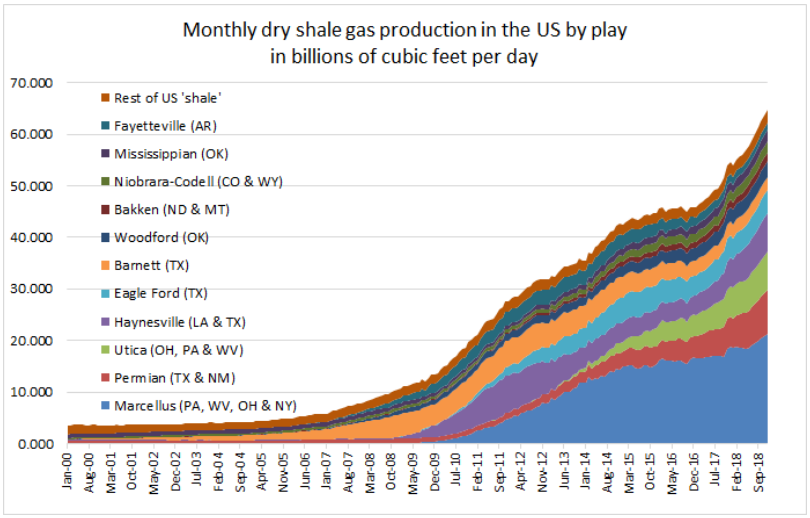

Figure 1: The shale gas boom

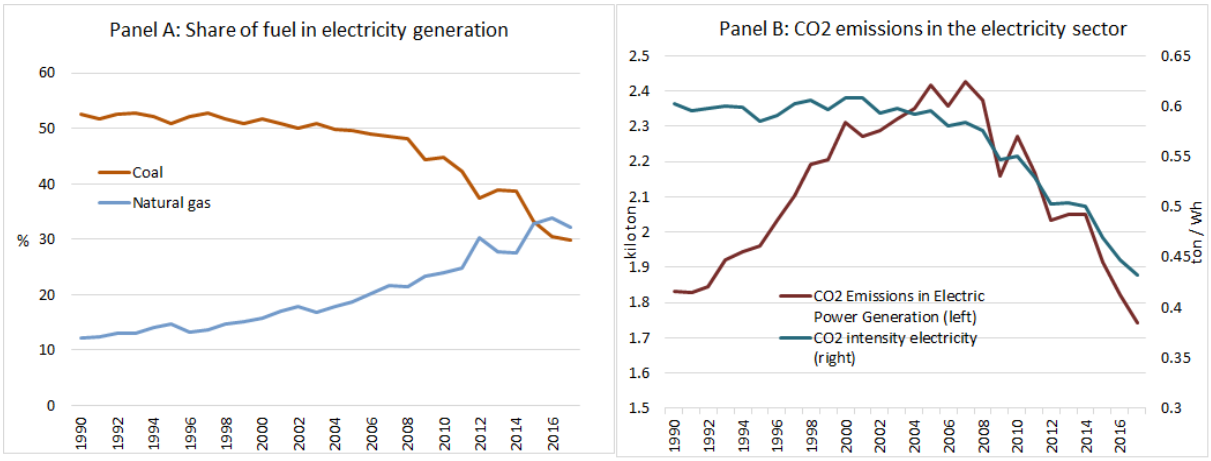

Figure 2: The shale gas boom in electricity

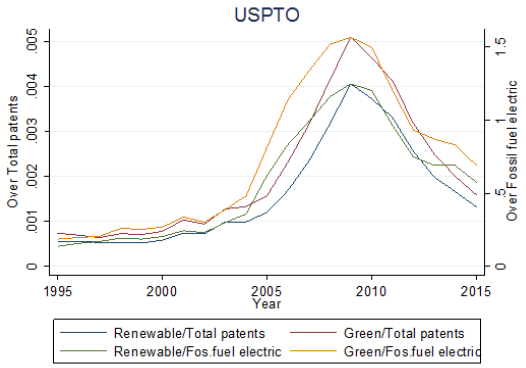

Figure 3: The collapse of clean innovation in electricity

of energy (think of eolian). Fossil fuel energy - coal or natural gas - are produced using a combination of resource use and an energy input (think of a power plant). The green energy is produced using only energy input. Resource use in energy production in turn generates pollution, with higher pollution propensity for coal than for shale gas.

We then use this framework to look at the short- and long-run effects of a shale gas boom defined as a one-time increase in the productivity of natural gas extraction. In the short run, there are two effects of a shale gas boom: a substitution effect and a scale effect. First, the substitution effect: a shale gas boom helps substitute natural gas energy for coal energy (which reduces emission) and green energy (which 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, the scale effect: a shale gas boom makes overall energy production cheaper which leads to an increase in overall energy consumption and therefore in aggregate pollution. The overall short-run effect of a shale gas boom is to reduce pollution when the substitution effect is negative and large enough compared to the scale effect, which occurs when coal is sufficiently more polluting than natural gas at the margin.

In the long run, a shale gas boom tends to postpone the switch toward green innovation, i.e. towards innovating in the energy input production technology for clean energy. 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.

Finally, to assess the short-run and long-run impacts of improving the shale extraction technology, we move to a quantitative analysis. We first calibrate the static version of our 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 renewable energies), and estimates from the literature on the elasticity of substitution across fuels in order to estimate the initial technology levels. Our preliminary results indicate that, for the United States, a reduction in the price of natural gas (akin to the "shale gas revolution") may lead to a decrease in CO_2 emissions (i.e. the intermediate technology has a positive environmental effect in the short-run). We then simulate a dynamic economy and show that for reasonable parameter values, the shale gas revolution decreases innovations in green technologies and increases emissions in the medium- and long-run.