Induced Innovation, Inventors, and the Energy Transition

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Mainstream models of directed technical change in the environmental macro literature assume a unit mass of scientists who choose between working in the clean and dirty sectors each period based on which sector will maximize their expected payoffs (e.g., Acemoglu et al. 2012; Lemoine 2017). This assumption implies that a sufficiently large subsidy to clean R&D can generate large-scale, rapid reallocations of scientific activity across sectors. These endogenous inventor-level decisions contribute to aggregate shifts in research output and affect the policy prescriptions generated by these models. Yet there is a shortage of empirical evidence to inform modeling assumptions about inventor transitions across sectors. We seek to fill that gap by providing new empirical evidence on historical inventor transitions between the clean and dirty sectors in response to changes in energy prices.

This research will extend prior work on induced innovation that has used data at the aggregate, industry, and firm level to provide evidence that innovation responds to energy prices (e.g., Aghion et al. 2016; Newell et al. 1999; Popp 2002). We will study how inventors transition across sectors in response to energy price shocks to elucidate the mechanisms underlying aggregate responses. In particular, we will focus on whether inventor-level transitions between the clean and dirty sector vary with inventors' backgrounds.

Our findings could have important implications for economic modeling and for policy. If individual inventors rarely transition across sectors, or if more specialized inventors are less likely to transition across sectors, then prior empirical evidence on induced innovation may understate the adjustment costs required for a large-scale shift into clean innovation. Our results may also point to the need for alternative policy instruments to increase the supply of inventors in clean innovation. If individual inventors cannot easily transition across sectors, targeted interventions that encourage students to pursue training in clean fields may be a more cost-effective means to generate a shift into clean innovation than a carbon price or an R&D subsidy.[2]

Data

Our analysis relies primarily on two types of data. First, we use patent data from PATSTAT. We will identify and extract information on energy-related patents from a range of technologies and classify the patents as relating to either clean or dirty technologies. We will then transform the patent-level data into inventor-level data. For each inventor, we will search PATSTAT to collect data on all the patents the inventor ever applied for as well as the firms the inventor patented for. The second type of data are price shocks that may induce innovation. We will use IEA's Energy Prices and Taxes data for tax-inclusive prices of coal, oil, and natural gas at the country-year level.

Descriptive Statistics

As an initial step we will use the data to document inventor-level patenting activity. In particular, we will quantify the extent to which individual inventors patent in both clean and dirty technologies within a year as well as how their patenting activity changes over time. We will also construct measures of whether a given firm specializes in clean or dirty patenting and quantify the rate at which individual inventors migrate between firms of different types. These descriptives will provide

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[2]This would be consistent with results from Bell et al. (2019), who find that early exposure to innovation has a large effect on whether individuals become inventors.

an initial characterization of how mobile inventors are across sectors before we test whether this mobility responds to factor price shocks, and whether this response varies with inventor experience.

Empirical Strategy

We will adapt the Poisson specification in Aghion et al. (2016) to analysis at the individual level, modeling clean energy patenting activity as follows:

$$PAT_{ijt} = exp(\beta_1 \ln P_{jt-1} + \beta_2^C A_{it-1}^C + \beta_2^D A_{it-1}^D + \beta_3^C \ln P_{jt-1} A_{it-1}^C + \beta_3^D \ln P_{jt-1} A_{it-1}^D + T_t)\eta_i + u_{ijt}.$$

PAT_{ijt} is the count of clean patents by inventor i working in firm j in year t. A_{it-1}^X summarizes the inventor's knowledge stock in either the clean or dirty sector ($X \in \{C, D\}$). The knowledge stock measure includes the individual's stock of patents as well as spillovers from colleagues at the same firm and co-inventors at other firms. η_i are inventor-level fixed effects. Finally, $\ln P_{jt-1}$ is a vector of firm-specific prices for primary energy sources (coal, oil, and natural gas) which we construct as weighted averages of country-level prices: $\ln GP_{jt} = \sum_c w_{jc} \ln GP_{ct}$, where GP_{ct} is the average tax-inclusive fossil fuel price in country c in year t from the IEA's Energy Prices and Taxes data. The weights, w_{jc}, capture variation in exposure of firm j to country c. We construct the weights based on the proportions of patents firm j applies for in different countries for a period before our main analysis. This strategy exploits geographic variation in energy prices over time due to fossil-fuel transportation constraints and country-specific fuel prices after accounting for common shocks through time fixed effects (T_t).

Conducting analysis at the inventor level has two main advantages relative to prior work. First, it could facilitate a decomposition of aggregate responses that result from reallocations of activity across clean and dirty sectors at the industry, firm, and inventor level. In particular, we will examine whether inventors increase clean patenting via switching firms. Second, this approach would provide microeconomic evidence of inventors' substitution across sectors to inform assumptions used in macroeconomic models. In particular, $\hat{\beta}_3^X$ would be used to test whether all inventors are equally likely to innovate in the clean sector in response to an energy price shock, or if inventors with more concentrated knowledge stocks within the dirty sector are less likely to innovate in the clean sector in response to an energy price shock. A large negative $\hat{\beta}_3^D$, for example, would indicate strong path dependency possibly driven by low substitutability of skills necessary to patent in dirty technologies and those necessary to patent in clean technologies.

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