Energy Economics 46 (2014) 522–530

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

Measuring climatic impacts on energy consumption: A review of the empirical literature☆

Maximilian Auffhammer [a,*], Erin T. Mansur [b,*]

[a] UC Berkeley and NBER, 207 Giannini Hall, Berkeley, CA 94720, United States
[b] Dartmouth College and NBER, Department of Economics, 6106 Rockefeller Hall, Hanover, NH 03755, United States

ARTICLE INFO

Article history:
Received 2 December 2012
Received in revised form 11 April 2014
Accepted 24 April 2014
Available online 6 May 2014

JEL classification:
Q41
Q54

Keywords:
Energy
Climate change
Adaptation

ABSTRACT

This paper reviews the literature on the relationship between climate and the energy sector. In particular, we primarily discuss empirical papers published in peer-reviewed economics journals focusing on how climate affects energy expenditures and consumption. Climate will affect energy consumption by changing how consumers respond to short run weather shocks (the intensive margin) as well as how people will adapt in the long run (the extensive margin). Along the intensive margin, further research that uses household and firm-level panel data of energy consumption may help identify how energy consumers around the world respond to weather shocks. Research on technology adoption, e.g. air conditioners, will further our understanding of the extensive margin adjustments and their costs. We also note that most of the literature focuses on the residential sector. Similar studies are urgently needed for the industrial and commercial sectors.

1. Introduction

This paper reviews the literature on the relationship between climate and the energy sector. The energy climate relationship is interesting as it is a great example of a feedback effect. The causal link from emissions due to the combustion of fossil fuels to deliver energy services to climate change is well established. However, hotter summers and warmer winters will change energy consumption and production patterns. A similar feedback mechanism is hypothesized in land use (Pielke et al., 2002). There are several ways in which climate may affect energy consumption. In the residential, commercial and industrial sectors one would, in a warmer world, expect higher cooling demand, which would lead to increased electricity consumption. On the other hand, fewer cold winter days would result in decreased heating demand, which would drive down demand for natural gas, oil and electricity. These are all demand side effects. On the supply side, one would expect increased use of natural gas on hot days, as some power plants become less efficient as well as higher natural gas consumption for generation due to higher electricity demand. During the winter, there might be a decrease in natural gas demand for generation due to lower electricity demand.

In this paper we survey the literature containing empirical papers published in peer-reviewed economics journals focusing on how climate, which is generally defined as a long run average of weather, affects energy expenditures and consumption. Most of the studies we found focus on electricity consumption in the residential sector. The coverage of the commercial and industrial sectors as well as studies on other fuels is most sparse. For example, we could not locate *any* empirical peer-reviewed economics papers on the effect of climate on energy supply.

The empirical estimates of climate sensitivity of the energy sector are typically used to predict the cost of climate change adaptation. Climate models predict a range of changes to temperature, precipitation, and other climate measures. Most models predict a significant increase in global average temperatures by the end of the current century for scenarios close to a business as usual emissions path (IPCC SRES Scenario A1fi (Nakicenovic and Swart, 2000)) or a slightly more optimistic emissions path (A2). Auffhammer et al. (2013) provide a detailed discussion of climate models and their use in the social sciences. Overall one expects that people heat less and cool more. This change in behavior will have both intensive and extensive margin components.

With regard to the intensive margin, several papers examine the short run response to weather shocks. A common finding in this

☆ We thank Dave Rapson and anonymous referees for comments. Auffhammer thanks the Environmental Protection Agency for support under subcontract Q000-1C-1697. All remaining errors are ours.

* Corresponding authors.
E-mail addresses: auffhammer@berkeley.edu (M. Auffhammer), erin.mansur@dartmouth.edu (E.T. Mansur).

http://dx.doi.org/10.1016/j.eneco.2014.04.017
0140-9883/© 2014 Elsevier B.V. All rights reserved.

literature is that usage patterns of existing capital, such as air conditioners, change in response to climate change. Over time, however, we posit that people will respond to climatic change along extensive margins. They may change purchasing decisions of appliances, switch fuel sources, and even building characteristics. In general, economists know less about these extensive margin adjustments than the intensive ones. While research shows that future generations will likely own more air conditioners, this is due to both price and income effects (Wolfram et al., 2012). There is a nascent literature examining the weather and climate responses of air conditioner adoption (e.g. Auffhammer, 2012, 2014).

The questions that researchers will continue to face include: How will climate change affect peoples' energy expenditures, choice of fuel sources, and buildings? How will people adapt to a new and continuously changing climate? What will be the transitional costs of adapting? Much of the uncertainty over the energy costs associated with climate change will inevitably depend on the future income distribution and technologies. Nonetheless, economists have made some progress in studying two complementary issues: first, how energy choices differ among households and firms located in different climates; and second, how a given consumer responds to weather shocks. From a policy perspective, studies of the intensive and extensive margin adjustments speak to different, yet related, policy measures. If one is interested in short run reductions of weather driven energy demand (e.g. peak load) information campaigns, peak pricing and direct load control may be effective ways to achieve reductions in consumption. If one is interested in controlling the extensive margin adjustment, efficiency standards, rebates for efficient appliances and insulation may be more effective. While we do not speak to policy in this paper directly, this is an interesting dichotomy. Below, we review this literature, discuss where the literature could head, and outline the policy implications.

To address this question, the ideal data set would provide information on how a given household consumes energy in randomly assigned climates, all else equal. Unfortunately, this perfect experiment is not feasible as people sort into their preferred climate. One could imagine trying to identify how consumers adapt to climate in three different ways. One is to look at how a given household's consumption changes when it relocates to a new climate. For example, how do military families' energy expenditures change when they are relocated to a new climate? This approach raises identification concerns regarding the reason why people move, and why they chose a new housing type. No paper has attempted to explicitly deal with the sorting approach to our knowledge.

A second approach that some economists use is to look at the cross-sectional variation in climate. Namely, if there are two seemingly identical households that are located in different climatic zones, one can then look at how their energy choices differ and ask whether these differences are correlated with climate differences. The main concern with this approach is that estimates are subject to omitted variables bias: unobservable differences in households may be correlated with climate. For example, Albouy et al. (2013) find northern households to be less heat-tolerant than southern households. Another issue with looking at cross-sectional data is that we do not get an appreciation of the transition costs of fully adapting to a new climate.

The third approach uses panel (or simply time series) variation to examine how energy consumption responds to weather shocks. Recent studies of this reduced-form, short run response include Deschênes and Greenstone (2011) and Auffhammer and Aroonruengsawat (2011, 2012b). These estimates could overstate the damages of climatic change since households can adapt to a gradually changing environment in ways that they would not adapt to short-run weather shocks (Deschênes and Greenstone, 2011). On the other hand, these estimates may understate the damages, as individuals may adapt along the extensive margins by purchasing additional capital equipment in the long run, which they might not have done in the time frame of the data.

The paper is structured as follows. Section 2 lays a theoretical foundation to understand the aim of this literature. Section 3 reviews the literature on cross-sectional climatic evidence and panel (or time series) evidence of weather shocks. In Section 4, we discuss the gaps in the literature and where the literature may head. In particular, we examine the need to incorporate the literature on technology adoption in the estimation of the energy effects of climate adaptation. Finally, Section 5 offers concluding remarks on the state of the literature and its policy implications.

2. Theory

Before examining specific papers in this literature, we provide a theoretical foundation to understand why households may change energy expenditures in response to climate change. Define the utility function for a household as follows:

$$U = U\left(\vec{E}, \vec{D}, Y; F_0(t)\right), \tag{1}$$

where $\vec{E}$ is a vector of energy sources like electricity, oil, and natural gas. $\vec{D}$ is a vector of durable goods that affect the marginal utility of energy use like refrigerators, air conditioners, and insulation. The other variables are a composite good Y, or numéraire, and the current distribution of (outdoor) temperature $F_0(t)$, or simply F_0. We could broaden the definition of F_0 to include other climate variables that would affect households' purchasing decisions. For example, humidity may affect a household's choice of air conditioning (part of $\vec{D}$), which has implications for its choices of energy sources and other durables.

A household will maximize utility by choosing $\vec{E}$, $\vec{D}$, and Y, subject to income (I), energy prices ($\vec{P}_E$), durables prices ($\vec{P}_D$), the price of the composite good (normalized to one), and its expectation of distribution of temperatures, F_0:

$$\max_{\vec{E}, \vec{D}, Y} \; U(.; F_0) \;\; \text{s.t.} \; \vec{P}'_E \vec{E} + \vec{P}'_D \vec{D} + Y \leq I, \tag{2}$$

where we denote the choices that maximize utility given the current climate as $\vec{E}^*(F_0)$, $\vec{D}^*(F_0)$, and $Y^*(F_0)$.

A household derives utility from $\vec{E}^*(F_0)$ and $\vec{D}^*(F_0)$, in part, because the household can control the interior temperature, t_{in}. The energy needed to attain t_{in} depends on the absolute difference between t_{in} and the exterior temperature t, given the set of durables: $\vec{E} = \vec{E}\left(|t_{in} - t|; \vec{D}\right)$.

Climate change, by definition, alters the probability $f(t)$ of experiencing temperature t on a given day. As a result, the distribution will change (gradually) from $F_0(t)$ to $F_\tau(t)$, or F_τ. In response, a household may choose to allow the interior temperature to vary with t. However, if it does maintain a constant interior temperature, then the change in expenditures measures the welfare effects of climate change (ΔW):

$$\Delta W = \vec{P}'_E \cdot \left(\vec{E}^*(F_\tau) - \vec{E}^*(F_0)\right) + \vec{P}'_D \left(\vec{D}^*(F_\tau) - \vec{D}^*(F_0)\right). \tag{3}$$

There are several caveats to consider. First, energy and durables prices may respond to climate change. Second, the transition may be costly, especially if unexpected climate change results in suboptimal irreversible investments. Third, the transition will occur over time requiring discounting of future costs. Fourth, this measure excludes how climate directly enters the utility function and therefore is only a part of the overall costs. Finally, households may relocate in response to climate change.

We can now compare this measure to what the literature estimates. Papers that use either time series or panel data measure how energy expenditures change with temperature. This measure is conditional on the