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Punctuated equilibrium and policy diffusion: An application to energy foundations

Équilibre ponctué et diffusion des politiques: une application aux fondations énergétiques

Fikret Atalay

School of Civil & Environmental Engineering, Georgia Institute of Technology, USA, fikret.atalay@gatech.edu

ABSTRACT: Scientists and engineers are often tasked with providing innovative solutions to challenging problems, such as energy, sustainability and climate change. One example in geotechnical engineering is energy foundations, which rely on ground-source heat pumps (GHPs) to facilitate heat transfer between the ground and the circulating fluid to provide heating and cooling in a renewable and sustainable manner. However, in addition to developing a technology to address a particular problem, it is also important to have an understanding of the public policy drivers leading to adoption of these innovations. After all, the true potential of a new technology can only be fully realized if the technology is widely diffused and put to use. In this regard, a case study is presented looking at the application of the Punctuated Equilibrium Theory and the Bass Diffusion Model (BDM) from social sciences to gain insight into GHP related policies across the U.S. between 2000 and 2015, as well as GHP adoption between 2002 and 2009. The results indicate that policies enacted at the federal level can act as a trigger for states to enact GHP related policies, and that BDM can provide valuable insights into the factors driving policy diffusion and market adoption.

1 INTRODUCTION

Punctuated equilibrium theory in social sciences is derived from the hypothesis in evolutionary biology, which suggests that evolution is marked by sudden shocks followed by periods of little or no change. In public policy, it refers to the fact that most policies are relatively stable over a long period, and that external shocks are a necessary (but not sufficient) condition to result in major policy change (Dunn, 2012). More recently, the concept of diffusion has been applied to social sciences such as marketing, sociology and public policy to model diffusion of innovations, ideas and policies following an external shock. It has been observed that in particular, “policy diffusion, with its S-shaped curve, is remarkably like a punctuated equilibrium model in which the system shifts rapidly from one stable point to another” (Baumgartner and Jones, 2009).

In science and engineering, diffusion is an important process describing the net movement of molecules and atoms from a region of high concentration to a region of low concentration. Heat transfer in and around an energy foundation is one example of the diffusion process in geotechnical engineering. Energy foundations are a variation of the traditional foundation system, where the foundation is fitted with fluid-circulating tubes and the relatively constant temperature characteristics of the ground are utilized to exchange heat energy between the circulating fluid and the ground, which remains at an approximately constant temperature of about 15 to 20°C as soon as depth reaches about 5 to 10 m (Brandl, 2006; Arson et al., 2013). The transfer of heat is achieved via the use of a ground-source heat pump (GHP), which requires electricity to operate. However, a typical heat pump can move 3 to 5 times as much energy between the ground and the building than it consumes while doing so (Hughes, 2008). As such, energy foundations used in conjunction with GHPs can provide a renewable and sustainable energy source for heating and cooling buildings, provided that an energy balance can be established between heat injection and extraction (Arson et al., 2013).

This paper presents a case study looking at the application of the punctuated equilibrium theory and policy diffusion to gain insight into GHP related policies in the U.S. between 2000 and 2015, as well as GHP adoption rates between 2002 and 2009. The policy data for this study were obtained from the Database of State Incentives for Renewables & Efficiency (DSIRE). This database was queried for all state and federal level policies (for both regulatory policies and financial incentives) between 2000 and 2015, which yielded a total of 589 GHP related policies

(including residential, commercial and public sectors). Data on the rated capacity (in HVAC tons) of GHP shipments, which is used as a proxy for GHP market adoption, between 2002 and 2009 (period for which data was available) was obtained from the Energy Information Administration (EIA)’s website.

1.1 Evaluation and Results

A distribution of the GHP related policies by year is shown on Figure 1. From Figure 1, a significant increase in GHP-related policies can be seen starting in 2006, with another small perturbation in 2009, then tapering off over the years. A closer examination of the dataset obtained from DSIRE revealed that in August 2005, the U.S. Congress approved the Residential Renewable Energy Tax Credit (which provided a 30% tax credit for GHP installations) with an effective start date of January 1, 2006. In addition, the American Recovery and Reinvestment Act of 2009, signed into law in February 2009, extended the 30% tax credit for residential GHP installations, and provided up to a 10% grant for commercial building installations.

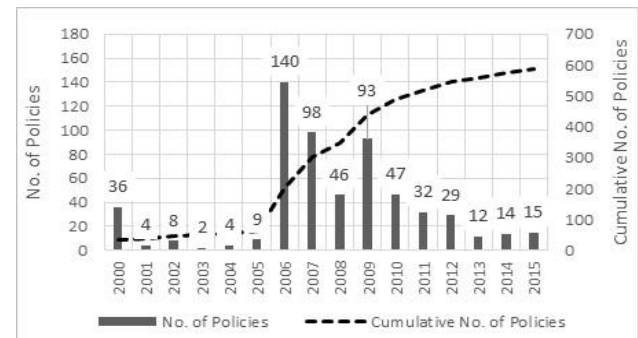


Figure 1. Distribution of GHP-related policies by year

It is hypothesized that federal policies acted as an external shock to the status quo at the time, and resulted in GHP related policies to be enacted at the state level. The Bass Diffusion Model (BDM) was used (Bass, 1969) in order to test this hypothesis. The BDM, also referred to as “mixed influence diffusion model”, has been used in the past to study both external and internal factors contributing to diffusion of technological innovations (Mahajan and Peterson, 1985; Rossman, 2009; Boushey, 2012). The model can be given in its differential form as follows:

$$dN(t) / dt = (a + b N(t)) [N^* - N(t)] \quad (1)$$

where N represent the number of policies, a represents the coefficient of external influence (e.g., external shock or innovation), b represents the coefficient of internal influence (e.g., imitation or word-of-mouth), and N^* represents the total number of units adopting the innovation. A high value of a indicates that external factors are driving diffusion, while a high value of b indicates that internal factors are driving diffusion.

Figure 2 shows the cumulative number of GHP related policies from 2000 to 2015, as well as the BDM results. The BDM coefficients that provided the best fit to the post-2005 data (after the federal tax credit was introduced) were $a = 0.23$ and $b = 0.08$. This indicates that external influence is the most likely driver of policy diffusion.

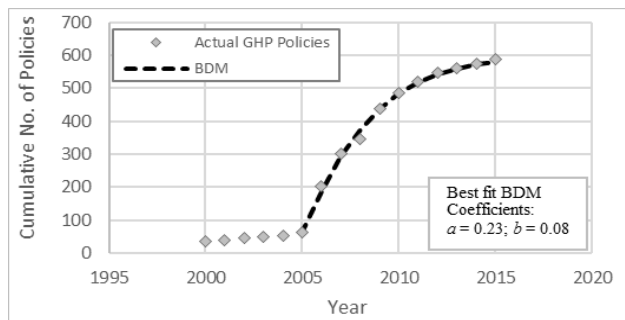


Figure 2. Cumulative number of GHP-related policies (2000-2015) and Bass Diffusion Model (BDM) Results

Figure 3 shows the cumulative rated capacity of GHP shipments from 2002 to 2009. In this case, the BDM coefficients that provided the best fit to the actual post-2005 data were $a = 0$ and $b = 0.63$. This indicates that internal influence (e.g., imitation or word-of-mouth) is the most likely driver of adoption.

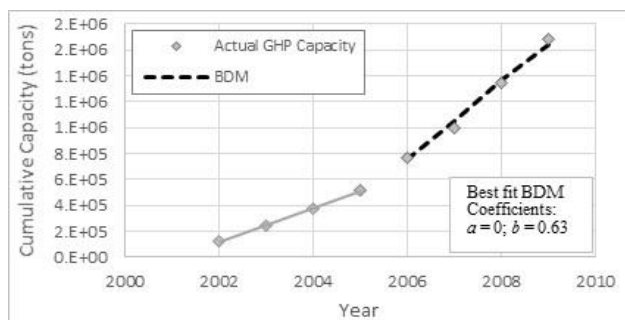


Figure 3. Cumulative rated capacity (in HVAC tons) of GHP shipments (2002-2009) and Bass Diffusion Model (BDM) Results

1.2 Discussion

These results can provide some important insights into the diffusion and market adoption of emerging technologies such as energy foundations. In this case, BDM results as shown in Figure 2 indicate that the introduction of a federal policy (tax credit) for GHPs in 2005 acted as an external shock, perturbing the equilibrium and driving the diffusion of policies at the state level, most likely due to policy mimicking by the states (Boushey, 2012).

Policy diffusion can in turn create awareness through signaling and information, leading to more widespread market adoption. Figure 3 shows that there was an increase in the adoption of GHPs after 2005 (as indicated by the steeper slope of the curve compared to pre-2005 levels), though in this case diffusion seems to be driven by internal factors and the increase in adoption rates is more gradual. Some likely causes for this observed behavior include higher initial costs relative to more conventional HVAC systems, as well as other market failures such as information asymmetry (e.g., potential buyers have

incomplete information with regards to the benefits and the drawbacks of the system), and split incentives between owners and building tenants (e.g., a commercial building owner has little incentive to use more efficient energy foundations coupled with GHPs when the renters are paying the energy bills).

State or local level policies can be devised to complement federal incentives to help overcome some of aforementioned challenges, and to further increase the rate of adoption of emerging technologies such as energy foundations. Examples of policy alternatives at the state or local level include tax credits, loans or grants to overcome high initial costs, or programs such as Property Assessed Clean Energy (PACE) which pays for 100 percent of a project's initial costs and the costs are repaid over a period of time with an assessment added to the property tax bill. Other policy alternatives include creating information programs to increase awareness and knowledge regarding emerging energy efficient technologies, or to provide property tax credits to commercial building owners to overcome the split incentives problem. Residential, commercial and public sector buildings will continue to be responsible for a large percentage of total energy consumption in the U.S., and policies can be crafted to encourage more widespread use of green technologies such as energy foundations coupled with GHPs for energy savings and subsequent reduction in carbon emissions.

2 CONCLUSION

The Bass Diffusion Model (BDM) has been applied to evaluate the diffusion of GHP related policies, as well as market adoption of GHPs in the U.S. The model results indicate that policies enacted at the federal level can act as a trigger and a signal for GHP related policies to be enacted at the state level. Increasing the market adoption is more challenging due to market failures such as high initial costs; however, policy alternatives can be devised at the state and local levels to complement federal incentives, to help overcome market failures, and to encourage more widespread adoption of emerging energy efficient technologies such as energy foundations.

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4 REFERENCES

- Arson, C.F., Berns, E., Akrouh, G., Sanchez, M., and Briaud, J.L. (2013). Heat Propagation around Geothermal Piles and Implications on Energy Balance, Materials and processes for energy: communicating current research and technological developments, A. Mendez-Vilas, Ed., p. 628-635.
- Bass, Frank M. (1969). "A New Product Growth Model for Consumer Durables." *Management Science* 15: 215-27.
- Baumgartner, F. and Jones, B. (2009). *Agendas and Instability in American Politics*. Chicago: University of Chicago Press.
- Boushey, Graeme (2012). Punctuated Equilibrium Theory and the Diffusion of Innovations. *The Policy Studies Journal*, 40(1): 127-146.
- Brandl, Heinz (2006). 'Energy foundations and other thermo-active ground structures', *Geotechnique*, 56: 81-122.
- Dunn, William N. (2012). *Public Policy Analysis*. Edition No. 5, Pearson Education Inc., Boston, MA, pp.460.
- Hughes, P.J. (2008). *Geothermal (Ground Source) Heat Pumps: Market Status, Barriers to Adoption, and Actions to Overcome Barriers*, Oak Ridge National Laboratory, Report ORNL/TM-2008-232.
- Mahajan, V. and Peterson, R.A. (1985). *Models for Innovation Diffusion*. Thousand Oaks, CA: Sage.
- Rossman, Gabriel. 2009. "The Diffusion of the Legitimate and the Diffusion of Legitimacy." *California Center for Population Research On-Line Working Paper Series*. University of California, Los Angeles.