TRANSITION DYNAMICS FOR ALTERNATIVE FUEL VEHICLES AND TRANSPORTATION FUELS

Jeroen Struben, MIT Sloan School of Management, Cambridge MA 02142, 514-796-4033, jjrs@mit.edu
David Chock, Yimin Liu, Margaret Whalen, and Sandy Winkler, Ford Motor Company, MI 48121

Overview

With oil prices at record levels, unprecedented US dependence on imported petroleum, and growing environmental concerns, the creation of economically sustainable markets for alternative fuel vehicles (AFVs) is vital to the success of automakers and the health of the US economy. Other economies face similar pressures. However, most efforts to introduce AFVs have failed or had very limited success. Diffusion of AFVs is complex, being both enabled and constrained by powerful positive feedback arising from various scale and scope economies and experience curves throughout the automotive and fuel supply chain, and from consumer behavior and word of mouth. Outcomes are strongly conditioned by decisions of energy companies, governments, automotive OEMs and their suppliers, and consumers. While such a transition will play out over decades, mobilization of resources within the next few years has long run consequences. Moreover, a successful transition to a self-sustaining AFV market requires intensive coordination between key decision-makers. Building on earlier AFV transition analysis, this research examines challenges for the development of self-sustaining AFV and fuel markets, and strategies for success. Specifically, we focus on the joint diffusion dynamics of and competition among AFVs powered by bio based feed stocks, (plug-in) electricity, hydrogen, and hybrid blends. We examine various policy, technology, and fuel pathway scenarios.

Methods

We develop a dynamic and spatially disaggregated model with a broad scope, grounded in economic, social-behavioral, operations management, and consumer demand theory. The fuel supply chain includes fuel markets, entry and exit of plants, installation and operating costs, and traces life cycle carbon- and energy intensities for each pathway. The model captures not only factors involving increasing returns, such as production learning and scale economies, but also diminishing returns, such as from land constraints on biofuel production. The model builds upon earlier work that focused on vehicle adoption dynamics including consumer acceptance of AFVs and changes in driver behavior in response to fuel cost and availability, the development of fueling infrastructure, and the evolution of vehicle attributes and auto OEM portfolios. The model confidence building process is supported by a rich data set with a variety of sources, including major auto and energy companies, and USDA, EIA and US Census. We further use calibration, extensive sensitivity analysis, and partial model testing.

Results

Preliminary results show a consistently long period before significant reductions in petroleum consumption or carbon emissions are achieved, even under aggressive carbon policies and optimistic technology scenarios, such as early and successful commercialization of carbon sequestration and storage. Other results are highly scenario specific. For example, technological spillovers across AFV platforms can strongly condition the dynamics of adoption (e.g., improvements in materials, software and battery technology developed for plug-in hybrids may benefit hydrogen fuel cell vehicles; hybrids and HFCVs could be powered by biofuels). Results also suggest that higher gasoline prices (whether caused by the market or policies to increase the market price of carbon) do not automatically lead to the rapid developing of a viable AFV market: higher fuel prices cause consumers to shift to more efficient conventionals, increasing the threshold AFVs must meet to become competitive. We demonstrate how the model can be used to examine how alternative fuel pathways and policies affect the viability of different strategies for the development of the AFV market and their impact on automakers, fuel suppliers, consumers, government, and the environment. Pathways include for example Biomass + Coal to Liquid (BCtL) or biomass to hydrogen (BtH), under varying policy and technology success climates, involving factors such as carbon pricing, carbon capture and sequestration (CCS), and the oil price.

Conclusions

Transitions to alternative energy in the transportation sector take long and are prone to failure. Achieving success requires an understanding of the detailed processes conditioning the dynamics, including alternative fuel pathways and their broader impact. Behavioral, dynamic models with broad scope can aid in doing so, as well as in strategizing for the development of the AFV market. We discuss the current and future steps.

Selected References

Argote, L. and D. Epple (1990). "Learning-Curves in Manufacturing." *Science* **247**(4945): 920-924.

Arthur, W. (1989). "Competing Technologies, Increasing Returns, and Lock-in by Historical Events." *Economic Journal* **99**(394): 116-131.

Bass, F. (1969). "A new Product Growth Model for Consumer Durables." *Marketing Science* **15**(5): 215-227.

Ben-Akiva, M. and S. Lerman (1985). *Discrete choice analysis : theory and application to travel demand.* Cambridge, Mass., MIT Press.

Berry, S., J. Levinsohn, et al. (1995). "Automobile Prices in Market Equilibrium." *Econometrica* **63**(4): 841-890.

Brownstone, D., D. Bunch, and K. Train. (2000). "Joint mixed logit models of stated and revealed preferences for alternative-fuel vehicles." *Transportation Research Part B-Methodological* **34**(5): 315-338.

Dagsvik, J. K., T. Wennemo, et al. (2002). "Potential demand for alternative fuel vehicles." *Transportation Research Part B-Methodological* **36**(4): 361-384.

Dargay, J. and D. Gately (1997). "Vehicle ownership to 2015: implications for energy use and emissions." Energy Policy **25**(14-15): 1121-1127.

Farrell, A., D. Keith and J. Corbett . (2003). "A strategy for introducing hydrogen into transportation." *Energy Policy* **31**(13): 1357-1367.

Fiddaman, T. S. (2002). "Exploring policy options with a behavioral climate-economy model." *System Dynamics Review* **18**(2): 243-267.

Greene, D., P. Patterson, et al. (2005). "Feebates, rebates and gas-guzzler taxes: a study of incentives for increased fuel economy." Energy Policy **33**(6): 757-775.

Greene, D. and S. Plotkin (2001). "Energy futures for the US transport sector." *Energy Policy* **29**(14): 1255-1270.

Katz, M. and C. Shapiro (1985). "Network Externalities, Competition, and Compatibility." *American Economic Review* **75**(3): 424-440.

Klepper, S. (1996). "Entry, exit, growth, and innovation over the product life cycle." *American Economic Review* **86**(3): 562-583.

Lovins, A. and B. Aranow (2004). *Winning the oil endgame : innovations for profits, jobs and security*. Snowmass, Colo., Rocky Mountain Institute.

McFadden, D. (1978). Econometric Models of Probabilistic Choice. *Structural Analysis of Discrete Data with Econometric Applications.* C. Manski and D. McFadden (eds). Cambridge, MA, MIT Press.

National Academy of Engineering (2004). *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs*. Washinton D.C., National Academy Press.

Ogden, J. (2004). Where will the Hydrogen Come From? System Considerations and Hydrogen Supply. *The Hydrogen Economy Transition: Moving Toward the Post Petroleum Age in Transportation.* D. Sperling and J. Cannon (eds.) Amsterdam, Elsevier Academic Press.

Sterman, J. (2000). *Business dynamics : systems thinking and modeling for a complex world.* Boston, Irwin/McGraw-Hill.

Struben, J. (2006). " Essays on transition challenges for alternative propulsion vehicles and transportation systems." Ph.D. diss,. Massachusetts Institute of Technology.

Struben, J. (2007). "Transition dynamics for alternative propulsion vehicle markets - model reference". Cambridge, MA. MIT project on transition dynamics for alternative propulsion vehicle markets. Report 1. Available from Author.

Struben, J. and John Sterman, (2008). "Transition Challenges for Alternative Fuel Vehicle and Transportation Systems". *Environment and Planning B.* **35**(6): 1070-1097.

Urban, G., J. Hauser and J. Roberts (1990). "Prelaunch Forecasting of New Automobiles." *Management Science* **36**(4): 401-421.

US Department of Energy (2004). *Transportation Energy Data Book (ORNL-6973)*, Edition 24, Oak Ridge National Laboratory Report, Oak Ridge, TN: October 2004