2015

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Recommended Citation

Young, Jesse D., "Economic and Policy Factors Driving the Adoption of Institutional Woody Biomass Heating Systems in the United States" (2015). *Graduate Student Theses, Dissertations, & Professional Papers*. 4496.
https://scholarworks.umt.edu/etd/4496

ECONOMIC AND POLICY FACTORS DRIVING THE ADOPTION OF INSTITUTIONAL WOODY BIOMASS HEATING SYSTEMS IN THE UNITED STATES

By

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Thesis

presented in partial fulfillment of the requirement
for the degree of

Master of Arts
in Economics

University of Montana
Missoula, MT

May, 2015

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Young, Jesse D. M.A., May 2015 Economics

Economic and Policy Factors Driving the Adoption of Institutional Woody Biomass Heating Systems in the United States

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New biomass combustion technologies and adequate biomass supplies have empowered the United States (U.S.) to look beyond satisfying heating needs with traditional fossil-based fuels, but biomass heating is often overlooked by many commercial and institutional entities. This study uses county level Zero Inflated Negative Binomial (ZINB) cross sectional regression analyses to identify economic factors that are favorable to the adoption of decentralized woody biomass heating systems by institutions in the U.S. In addition, biomass policy efficacy with respect to decentralized biomass heating systems is analyzed and regression results are used to develop an expansion map that highlights counties in the U.S. that may be good targets for biomass heating. Across all three models higher heating degree days, population density, and available forest residues decrease the odds of a county not containing an institution using a decentralized biomass heating system, with forest residues being the best predictor. When predicting the likely count of institutions using biomass heating systems, heating degree days, commercial natural gas prices, median house value, available biomass from lands treated under the National Fire Plan, and the proportion of Forest Service land have statistically significant coefficients that are positive. An increase in each of these variables is positively associated with an increased likelihood of one or more institutions using biomass. State policies in support of biomass use were shown to have a negligible effect on the number of decentralized biomass heating systems, while procurement policies related to utility infrastructure and renewable products and fuels specifically have a negative association. It is worth noting that, though level of active management resulting in biomass production is not a policy variable per se, it has important policy dimensions. Both federal land management practices and resources allocated to fuel treatments under NFP are highly subject to public policy decisions, including budget allocations for forest restoration and fuels treatments. Future expansion in the use of decentralized biomass heating systems is predicted to be most successful in counties in the Northwest and Northeast, and to a lesser degree in counties in the states of Michigan, Colorado, and New Mexico.

Acknowledgments

I would like to express my sincere gratitude to Dr. Helen Naughton who has spent countless hours giving me guidance on methodology and writing structure that has refined my theses into a document worthy of the University of Montana's excellent academic reputation. With Dr. Naughton's help I have grown from a novice economist, as I have acquired a number of new credentials that will serve me well in a career as a multidisciplinary researcher. I am also deeply appreciative to Dr. Katrina Mullan for her many insights in economic theory that have strengthened this body of work. Dr. Mullan's time and effort have been paramount in the successful completion of this project from its infancy, starting with my attendance in Empirical Research Design during my first year of graduate school. I would also like to extend a profound thanks to Dr. Nate Anderson for his guidance on factors that carry heavy influence on active forest management and the wood products industry, as well as giving me the opportunity to pursue a career in conservation with the Rocky Mountain Research Station of the United States Forest Service. Dr. Anderson's advice in data collection and endless hours of mentoring beginning in the spring of 2012 have been priceless in the development of both this body of work and my research credentials. To my thesis committee as a whole I express my deepest gratitude for your guidance through this process.

I am also very thankful to the Biomass and Research Development Initiative (BRDI) of the USDA National Institute of Food and Agriculture and to the National Fire Plan (NFP) of the US Forest Service for funding my research through the Rocky Mountain Research Station while enrolled in the University of Montana's Masters of Economics program. Without this support attending this program would not have been feasible. I would also like to thank the University of Montana Economics Department for the financial support I received during the 2013-2014 school year.

Finally, I would like to thank my friends and family for all of their support through my academic career, especially that of Ashley Walters who most notably had to endure endless hours of economic jargon over the last six years.

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Introduction

New biomass combustion technologies and adequate biomass supplies have empowered the United States (U.S.) to look beyond satisfying heating needs with traditional fossil-based fuels, but biomass heating is often overlooked by many commercial and institutional entities. In recent years there has been increasing attention paid to expanding the institutional adoption of decentralized woody biomass heating systems by projects like the Fuels for Schools program (Farr and Atkins, 2010). While this program and many like it have had a number of success stories, there have also been some failures due to inaccurate targeting of adopting locations. This study uses a Zero Inflated Negative Binomial (ZINB) cross sectional regression analysis to identify economic factors that are favorable to the adoption of decentralized woody biomass heating systems by institutions in the U.S. In addition, policy efficacy with respect to decentralized biomass heating systems is analyzed and regression results are used to develop an expansion map that highlights areas in the U.S. where efforts encouraging these systems are likely to be most effective.

In the face of volatile energy prices and climate change, renewable energy production is seen as a means to reduce greenhouse gas emissions and ensure affordable energy is available in the future. One source of renewable energy is heat, electricity and fuels produced from biomass. Biomass is defined as “organic non-fossil material of biological origin constituting a renewable energy source” (U.S. EIA, 2014a). Forest-derived biomass specifically refers to “wood residues obtained directly from the forest or indirectly from wood manufacturing and processing factories or urban waste” (Shelly, 2014) and is referred to as woody biomass throughout the remainder of this paper. Woody biomass can be used to produce a wide range of products, but in most cases use of biomass as raw material is costly and difficult due to low material quality, low bulk density, and heterogeneous size and composition (Shelly, 2014). Worldwide there are emerging markets that utilize inferior woody biomass for energy and heat production using wood pellets as a fuel source (Vakkilainen, 2013; Qian and McDow, 2013). In the U.S., the most widespread use of woody biomass is in the industrial sector, which includes wood pellet production and constitutes 68% of the woody biomass energy market (Vakkilainen, 2013; U.S. DOE, 2011). However, in Europe woody biomass is more widely used for institutional and district heating applications. For example, Austria and Sweden experienced a six and eightfold increase, respectively, in biomass district heating during the first decade of the 21st century largely due to federal and local policy incentives (Dong et al., 2009). In the U.S. advances in the institutional sector are tied to technology adoption, which has been slow to respond to policy incentives.

Over the last couple of decades great advances have been made in distributed-scale biomass combustion and co-firing technologies (Batidzirai et al., 2013; Bridgewater et al., 2002; Dong et al., 2009; McKendry, 2002; Wood and Rowley, 2011), which have provided the means for institutions to look beyond fossil fuels and install new innovative systems that use locally sourced woody biomass as a primary fuel source. The natural resources needed to sustainably expand the use of woody biomass for energy in the U.S. have been quantified in a number of previous studies (Greg and Smith, 2010; Rummer et al., 2005; U.S. DOE, 2011). Furthermore, using woody biomass as a fuel source can offer a means to improve forest conditions by providing markets for low-grade materials produced from thinning overstocked forests and removing dead and diseased trees (Dykstra et al., 2008; Noss et al., 2006). Poor forest conditions are in part driven by a disruption of natural fire cycles caused by a century of successful low intensity wildfire suppression, which has resulted in overgrown forests with increased fuel loads putting them at increased risk of experiencing high intensity wildfires (Polagye et al., 2007; Raffa et al., 2008; Rummer et al., 2005). In addition, if biomass is sourced from sustainably managed forestland, using biomass as a primary fuel source is unlikely to result in a net contribution of carbon dioxide (CO_2) greenhouse gas emissions to the atmosphere, and may actually reduce CO_2 emissions through both the reduction of emissions from the open burning of logging slash and of the offset of fossil fuels (Favero and Mendelsohn, 2014; Loeffler and Anderson, 2014; Malmsheimer et al., 2008; Nicholls et al., 2006). Other benefits of expanding biomass as a fuel source include increased employment opportunities, air quality benefits, and the diversion of woody waste materials destined for landfills (Nicholls et al., 2006).

However, forest biomass energy is not without risk or controversy. Major challenges surrounding biomass utilization include many ecological concerns of negative effects on the landscape. Ecological concerns include the pollution of our waterways as a result of erosion from logging and thinning operations, localized air pollution of particulates from biomass combustion, reduced quality of soils due to nutrient removals associated with excessive removal of biomass, and reductions in biodiversity (Fernando et al., 2011).

In addition to ecological concerns, there are also economic challenges of using woody biomass that have to be overcome in order for a healthy biomass market to emerge. The current market value for woody biomass energy in the U.S. is estimated at $6.5 billion (Summit Ridge, 2007) and can be segmented into four sectors: 1) *forest products industry*, 2) *residential heating*, 3) *electric power generation*, and 4) *commercial heating* (U.S. EIA, 2009; U.S. EIA, 2010). The commercial heating sector includes the decentralized institutional heating systems that are the subject of this study. The forest products and residential heating sectors are the largest consumers of woody biomass, consuming 68% and 20% of total biomass in the market, respectively (U.S. DOE, 2011). Both sectors have been studied extensively and economic incentives that drive the market have been identified (Aguilar et al., 2011; Hardie and Hassan, 1986; Ince, 2000; Song et al., 2012a). On the other hand, the electric power and commercial heating sectors have been given less attention by researchers and consume a smaller portion of total biomass at nine percent and three percent, respectively (U.S. DOE, 2011). In recent years there has been an increased interest in the electric power sector, both in identifying economic incentives and identifying counties with high estimated potential for cofiring biomass with coal in utility boilers (Aguilar et al., 2012; Goerndt et al., 2013), as well as analyzing the performance and viability of relatively new combustion, gasification and pyrolysis systems (Bridgewater et al., 2002; McKendry, 2002). Less is known about economic incentives in the commercial heating sector, at least partly because such incentives cannot be easily separated from those driving the electric power sector after 1990 (Aguilar et al., 2011).

This study expands the knowledge of the commercial sector by focusing on the economic and policy factors that individual institutions appear to take into consideration when deciding whether or not to adopt a woody biomass heating system. Both state and federal policy efficacy with respect to decentralized biomass heating systems are analyzed to inform the future development and adoption of policies designed to expand the biomass heat industry that is currently in a period of expansion. State policy is explicitly analyzed while federal policy is analyzed implicitly through the implementation of federal policy, which widely dictates energy regulation and federal forest management practices. In addition, this analysis will inform stakeholders at the federal, county, and institutional levels of key economic factors that catalyze the adoption of biomass heating systems. An industry expansion map of in-sample predictions will inform personnel in federal agencies of counties where efforts encouraging biomass heating systems are likely to be most effective. Officials at the county and institutional levels can use this information to determine if they are ideally positioned to adopt a biomass heating system and pursue federal grants, while federal agencies can use this information to efficiently allocate resources. In addition, this analysis will serve as a base case for future exploration into the effects of barriers and limiting factors of woody biomass heating systems. A cross sectional retrospective analysis is performed and future expansion paths for institutional biomass use are presented. The scope of the analysis is all fifty states in the U.S., using county and county equivalents as the observational units. The structure of this paper is as follows: 1) literature review, 2) a discussion of the theoretical framework of industry location, 3) the purpose and goals of the study, 4) a discussion of methods and data, and 5) presentation of results, followed by 6) a discussion and conclusion.

Literature review

A Brief History of Biomass Use in the U.S.

Traditional biomass fuel sources such as fuelwood and charcoal, agricultural residues, and animal dung played an important role in the pre-industrial age, representing 99% of U.S. primary energy consumption in the early 19th century (Victor and Victor, 2002). Primary energy is defined by the U.S. Energy Information Administration (2012) as “energy in the form that it is first accounted for in a statistical energy balance, before any transformation to secondary or tertiary forms of energy”. Examples of this would be crude oil before it has been refined to its many end products, or roundwood logs that have not been chipped or transformed into wood pellets. During the industrial revolution from 1850 to 1910, biomass fuel use declined rapidly, at first driven by increasing water mill use followed by the attractive lure of high energy fossil fuels; most notably coal (U.S. EIA, 2014b; Victor and Victor, 2002). By 2002, the biomass share of primary energy consumption and production in the U.S. had reached a low point of 2.42% and 3.29%, respectively (AEO, 2005). By 2012 biomass’s share of energy consumption and production had grown reaching 2.66% and 4.78%, respectively, accounting for 22.95% of the primary non-fossil energy produced in the U.S when including both hydro and nuclear power (AEO, 2014).

Increased biomass consumption in the modern era has not been equal across all sectors for a variety of reasons, as each sector responds to different economic incentives. One recent study shows that biomass as a fuel source in the industrial sector has a strong positive correlation with the production level of paper and pulp mills, and to a lesser degree oil prices (Aguilar et al., 2011). Large forest industry facilities have a long history of using combustion boilers for co-generation of heat and power using both waste wood and pulping byproducts like black liquor as fuel. The strong link between industrial biomass consumption and paper and pulp production appears to leave little room for outside policy forces to impact the industrial sector’s level of biomass consumption. However, some federal subsidies for biomass utilization have impacted this sector. For example, the Food, Conservation, and Energy Act of 2008 (i.e. the 2008 Farm Bill) authorized the Biomass Crop Assistance Program (BCAP), which matched payment for the first $45 per dry ton of biomass procurement costs of existing biomass stocks for qualified facilities that convert biomass to heat, power, bio-based products or liquid biofuels (FSA, 2013). In addition, BCAP provided up to 75% of the yearly cost of establishing a biomass supply source of herbaceous crops and woody crops for the first 5 and 15 years, respectively (FSA, 2013).

In contrast to biomass consumption in the industrial sector, residential biomass consumption trends are closely tied to competing energy prices and to a lesser degree government policies, showing a lagged positive correlation with competing energy prices (Aguilar et al., 2011; Hardie and Hassan, 1986; Song et al., 2012a). High correlation between competing energy prices and residential biomass consumption is due to urbanization and convenience. As urbanization increases access to locally sourced biomass, especially cut firewood, is reduced (Song et al., 2012b), in part, due to urban sprawl increasing the distance to productive lands, such as working forests and woodlands, and depleting local stocks and flows of biomass. In addition, as the U.S. has expanded infrastructure needed to reliably and consistently heat homes with cheap fossil-based fuels, the U.S. consumer has moved from traditional biomass fuels to cheaper fossil-based fuels (Song et al., 2012b). Following the oil spike of 1973 residential consumption of biomass for heat increased as a share of energy consumed in the U.S. before declining to four percent in 1997 (Aguilar et al., 2011), where it is expected to remain unless policies are passed making biomass fuels more cost competitive (Song et al., 2012b).

In contrast, economic incentives driving biomass consumption in the electric power and commercial sectors cannot be easily separated. Biomass use in these sectors is not driven by higher priced alternative fuels or increased energy costs alone, but is also affected by regional government incentives through a variety of policy instruments (Aguilar et al., 2011; Song et al., 2012a). Policy instruments are defined by Vedung (1998, p. 21) as a “set of techniques by which government authorities wield their power in attempting to ensure support and effect or prevent social change”. Looking to history for an example, the energy and commercial sectors were slow to respond to the oil price hikes of 1973, and did not increase woody biomass fuel use as a substitute for fossil fuels until the late 1980s, when there was a shift in business practices as power plants and commercial firms began to respond to government policies (Aguilar et al., 2011). Without government incentives, woody biomass is not seen as a viable fuel source unless the most favorable economic, geographic and technological conditions apply (Skog et al., 2006). Policy incentives enacted through federal and state governments, as well as federal agencies can increase the viability of woody biomass by reducing the economic costs of production (Dykstra et al., 2008).

European Influences on U.S. Markets

For a more recent example, public policies and financial incentives in the European Union (EU) intended to reduce emissions of greenhouse gases have had a major impact on industrial wood pellet production in the U.S., especially in the U.S. South (Qian and McDow, 2013). Ninety percent of wood pellet trade between the U.S. and Europe is with the United Kingdom (UK), the Netherlands and Belgium, with the fastest growing market in the UK, which consumed 9.8

million tons of wood pellets in 2010, up from 3.8 million tons in 2005 (Qian and McDow, 2013; Verhoest and Ryckmans, 2012). Increased wood pellet trade between the U.S. and Europe's top three importers is, in part, possible due to adequate port capacity of EU trading partners (Verhoest and Ryckmans, 2012), as well as adequate production capacity in the U.S. and Canada.

Policy Influence on Energy and Commercial Sector Use of Biomass in the U.S.

One of the most notable biomass policies enacted on the federal level in the U.S. is the Public Utility Regulation Policies Act (PURPA) of 1978, which encouraged biomass use in the energy sector through enhancing the cost energy competitive advantage by offering a high biomass "avoided cost" purchasing price (Aguilar et al., 2011; PURPA, 1977). In practice, PURPA required current energy utility providers experiencing a deficit in production to purchase existing renewable energy from other local providers at a cost that is equal to the cost of increasing output with additional fossil-fuel boilers. PURPA effectively forced the utility sector to purchase existing renewable energy to meet demand before they were allowed to expand using traditional fossil-fuels. Other policy programs that helped stimulate consumption of biomass in the commercial sector include:

- the federal renewable energy production tax credit (PTC) established by the Energy Policy Act of 1992 for closed-looped biomass[1] electricity plants (EPACT, 1992), which was extended with the American Jobs Creation Act of 2004 to include open-looped biomass[2] (AJCA, 2004);
- the federal business energy investment tax credit (ITC) for energy projects and combined heat and power projects expanded by the American Recovery and Reinvestment Act (ARRA) of 2009 as an alternative to PTC program (ARRA, 2009);
- the Renewable Energy Grant Program, where grants can be claimed for energy investments if construction began between 2009 and 2010 and is operational before 2016 (DSIRE, 2014);
- guaranteed loans for commercial or non-federal energy investment programs offered through the Department of Energy (DOE) (Aguilar et al., 2011);
- and government bonds like the Clean Renewable Energy Bonds (CREBs) and the Qualified Energy Conservation Bonds (QECBs) (DSIRE, 2014; EPACT, 2005).

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[1] Organic material grown with the sole purpose of being converted into bioenergy at a qualified facility (EPACT, 1992).

[2] Organic material from forest related resources including mill and harvesting residues, pre-commercial thinning, slash, brush and solid wood waste materials used to power electricity plants (e.g. waste pallets, crates, dunnage, manufacturing and construction wood wastes and landscape or right of way tree-trimming) (AJCA, 2004).

While federal policies have major influence on the biomass market in the U.S., state policies better reflect local and regional attitudes towards biomass use, as well as the unique challenges faced within local biomass markets (Aguilar and Saunders, 2010).

Many states have designed and implemented policies aimed at making woody biomass consumption economically viable in the commercial and electric power generation sectors. In the 1980s, California aggressively pursued biomass energy production policy with the help of the initiative called Interim Standard Offer 4 (ISO4), which provided guaranteed rates for bioenergy facilities for a limited time (Dykstra et al., 2008). While more recently in 2008, Michigan passed the Clean, Renewable, and Efficient Energy Act (Public Act 295) to strengthen its renewable energy sector (Leefers, 2011). Both California and Michigan are also among 37 states and the District of Columbia that have adopted state Renewable Portfolio Standards (RPS) to strengthen their commitment to renewable energy production (DSIRE, 2014). Other policy instruments encouraging biomass consumption that have been passed in states around the nation include tax incentives, cost share and grant programs, rules and regulations, financing policies, procurement policies, and technical assistance programs (Becker et al., 2011b).

State polices encouraging woody biomass for energy use are explicitly quantified in this study to see what effect these have on the likelihood of institutional biomass consumption. Policy classifications for this study were derived from Becker et al. (2011b) and are highlighted in Table 1. The literature often cites that a lack of cost share, grants, and financing as a barrier to development of new biomass facilities due to high start-up costs and long payback periods (Paepe, et al., 2006; Thornley, 2008), but this hypothesis has not been adequately tested in decentralized biomass heating facilities. However, small biomass facilities can be both incentivized and supported with financial instruments because small biomass facilities often require substantially less expensive technology, engineering and logistics expertise when compared to their large counterparts (Thornley, 2008).

Other major players in woody biomass policy are federal land agencies that administer large portions of federal land suitable for woody biomass production (CRS, 2012; U.S. DOE, 2005). The U.S. Federal Government owns about 640 million acres, which accounts for roughly 28% of the 2.27 billion acre land base in the U.S. (CRS, 2012). Approximately 93% of federal holdings are in western states consisting of 47% of the land base in the 11 contiguous western states and 62% of the land base in Alaska (CRS, 2012). The Bureau of Land Management (BLM) administers the largest portion of federal land holdings at 247.9 million acres[3], followed by the U.S. Forest

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[3] In addition the BLM administers 700 million acres of mineral rights in the U.S. (CRS, 2012).

Service (FS) at 192.9 million acres, the Fish and Wildlife Service (FWS) at 88.9 million acres[4], the National Park Service (NPS) at 79.7 million acres, and the Department of Defense (DOD) at 19.5 million acres (CRS, 2012). The Bureau of Indian Affairs (BIA) administers and manages 55 million acres[5] for 566 federally recognized American Indian tribes and Alaskan Natives in the U.S. (U.S. DOI, 2014), while the Bureau of Reclamation (BOR) owns over 5.1 million ft^2 of building space, and manages 2,538 buildings, 308 recreation sites, 343 dams, and 58 hydroelectric plants (U.S. DOI, 2000). With these assets the BOR supplies 10 trillion gallons of drinking water each year to 31 million people, as well as irrigation water for 140,000 western farmers, roughly one in five (U.S. DOI, 2000).

However, federal holdings include non-forest land and reserve lands, neither of which are a significant source of woody biomass. Forest biomass production generally occurs on lands that are forested and in non-reserve status (e.g. not wilderness or otherwise administratively restricted from harvesting). Of the 751.2 million acres of forest land in the U.S., 68%, or 514.2 million acres, are classified as timberland, which can be used for the production of commercial wood and fiber products (U.S. Census Bureau, 2012). About 22% of the nation's timberlands are publicly owned, with 78% in private ownership (U.S. Census Bureau, 2012), but ownership patterns vary widely across the country.

The four largest land agencies have distinct land management responsibilities that direct how natural resources can be used. The BLM and FS both have multiple-use, sustained-yield mandates for a variety of land uses including, but not limited to energy development, timber production, grazing, recreation, watershed protection, and conservation of wildlife and fish habitats (CRS, 2012). On the other hand, the FWS and NPS have narrow primary use mandates with the FWS following a mission to conserve plants and animals, with priority uses of recreation, hunting, and fishing given preference over consumptive activities like logging and mineral extraction, which are rarely allowed and must be compatible with the habitat requirements (CRS, 2012). The NPS prohibits the harvesting or removal of resources and follows a dual mission of preserving unique resources and providing public access for enjoyment (CRS, 2012). While each land agency has biomass resources at their disposal, their land management responsibilities affect how and at what rate these resources can be removed, leaving few options for obtaining woody biomass supplies from lands administered by the FWS and NPS, and many other lands that are legally or administratively off limits to harvesting.

In addition to the consideration of land management responsibilities, federal agencies have implemented a number of federal policy instruments that encourage the removal and use of

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[4] In addition the FWS administers many large marine areas (CRS, 2012).

[5] In addition the BIA administers 55 million acres of mineral rights in the U.S. (U.S. DOI, 2014).

woody biomass resources (Becker et al, 2009a). Leading the efforts are the FS and BLM in conjunction with the Department of Energy (DOE). Together these agencies carry out actions such as awarding grants to businesses, schools, Indian tribes and others, conducting research, and providing education to the public (U.S GAO, 2005). The authority to carry out such activities has been granted with the passage of federal policies including:

- the National Fire Plan (NFP), which was developed in response to the extreme fire season of 2000 in an effort to reduce biomass fuel loads surrounding at risk communities (Dykstra et al., 2008; NFPORS, 2014);
- the Biomass Research and Development Act of 2000 that coordinated bio-based research and development efforts and established the Biomass and Research Development Initiative (BRDI), which gave federal agencies the authority to provide grants, contracts, and financial assistance for research efforts (Pub. L., 2000);
- the Healthy Forest Restoration Act of 2003 aimed at returning the forest to a healthy state and reducing the risk of devastating wildfires (Pub. L., 2003);
- and the billion ton initiative and billion ton update, where the FS and DOE evaluated the potential of biomass displacing fossil fuels (U.S. DOE, 2005; U.S. DOE, 2011).

Over the last four decades the above policies and programs in the U.S. have made woody biomass more economically attractive.

Forest Management and Solid Biomass Fuels

While federal policies enacted through government agencies can influence woody biomass use, active forest management is a prerequisite for the production of solid biomass fuels used in decentralized woody biomass heating systems. In other words, the induced demand for locally sourced biomass heat depends on the demand for local, active forest management, which creates inputs for the former. Forest management varies widely across the U.S. due to a number of characteristics such as land cover type, productivity, harvesting schedules, ownership patterns, geographic barriers like rugged terrain and steep slopes, and economic barriers like access to raw material and markets. These characteristics result in a wide range of forest based products. Forest products commonly thought to be ideal candidates as fuel for biomass boilers in decentralized heating systems include sawmill residues, chipped roundwoods, chipped or ground slash piles, and manufactured wood pellets.

Each of these products has different characteristics that affect their combustion efficiency. Of particular importance is choosing a feedstock that has a low moisture content, low ash content, and high energy density (i.e. British Thermal Units (Btus) per pound). If the feedstock's moisture content is too high it will combust inefficiently at lower than ideal temperatures, and if it is too low there will be increased particulate matter emissions (BERC, 2006; Maker, 2004). In addition, feedstock moisture content varies based on wood density with hard woodchips averaging around 40% and soft woodchips averaging around 50% (Maker, 2004). The ideal moisture content for biomass combustion is around 30%, which is achieved by a drying process (e.g. kiln dry or air dry) (BERC, 2006). Along with moisture content it is also important to keep ash content in the feedstock as low as possible for a variety of reasons. Ash accumulation in a combustion boiler system must be removed regularly or it will cause unwarranted wear and tear on the system, inefficient heat transfer, and increased stack temperatures (Maker, 2004). In part, increased ash content is driven by feedstock that is either contaminated with dirt and debris, has a high proportion of bark, or is of a species that has a naturally high mineral content (BERC, 2006). A final feedstock characteristic of interest is energy density. The difference in energy content between hardwoods and softwoods is driven by two properties. First, since hardwoods have lower moisture content they retain more of their weight after being dried to 30% moisture content (Maker, 2004). Second, the average softwood is 10% less dense than the average hardwood and in the case of white pine can be as much as 35% less dense (Maker, 2004). Therefore logistics of storage and handling tend to be more efficient and less costly on a per unit basis for hardwoods. The higher wood density along with lower moisture content of hardwood results in hardwoods containing significantly more energy by weight, or Btus per pound. More broadly, all biomass is not equivalent when it comes to its potential as fuel.

A study carried out by the Biomass Energy Resource Center (BERC, 2006) for New Mexico sheds some light on which of the contending feedstock sources would be best suited for biomass combustion after being dried to 30% moisture content. Sawmill residues are the highest quality feedstock available with a specified total ash content of 3% of dry matter base and a minimum Btus per pound of 5,500 based on the lower heating value (LHV) (BERC, 2006). The next best feedstock is chipped small diameter logs with a maximum ash content of 7% of dry matter base and 4,750 Btus per pound LHV, followed by chipped whole trees with a maximum ash content of 8% of dry matter base and 4,500 Btus per pound LHV, and chipped slash with a maximum ash content of 10% of dry matter base and 4,000 Btus per pound LHV (BERC, 2006). Pellets are also used in many decentralized biomass heating systems, but cannot be easily compared to residues or chipped feedstock as these are manufactured and have a much high price per Btus per pound (Maker, 2004). Pellets come from many different tree species in different forms, including softwood pellets, hardwood pellets, and bark pellets. Softwood pellets have an average moisture content of 9.6% and an average 6,892 Btus per pound LHV, while hardwood pellets have an average moisture content of 12.3% and an average 7,061 Btus per pound LHV (Telmo and Lousada, 2011). In general wood pellets have an ash content of 0.5%, and Bark pellets have an ash content of 3.7%, a moisture content of 7.8%, and 8,641 Btus per pound LHV (Johansson et al., 2004). The relatively high cost of pelletization comes with benefits of higher energy density and uniformity that facilitates logistics, especially handling and storage.

While some fuels are better suited for combustion boilers than others, the main objective of procurement for decentralized biomass heating systems is to obtain suitable locally sourced biomass at the lowest price possible (Maker, 2004). This means different feedstock will be used in different regions as dictated by local silvicultural systems and forest management practices. Some common biomass flows are residues from logging operations and processing, as well as the residues from the wood product industry (Maker, 2004). These flows will be common where there is a strong forest products industry, while other biomass flows, like urban arboriculture wood waste for example, are more regional in nature. Refer to Figure 1 for U.S. regions used in this study.

States in the Northwest, West Coast, and Southwest have large amounts of federal land holdings, but experience additional difficulty obtaining materials due to geographic barriers like steep rugged terrain or long haul distances to markets (Maker, 2004; Skog et al., 2006; U.S. DOE, 2005). On the other hand these regions enjoy additional biomass flows that are produced as a result of NFP fuel treatments (NFPORS, 2014). The Midwestern region of the country is dominated by agriculture and rangeland and has relatively few federal land holdings and limited forest resources (CRS, 2012; USDA, 2007; U.S. DOE, 2005). The characteristics of the Midwest have stifled widespread use of wood resources as a fuel source with a few exceptions (i.e. Missouri) (W2E, 2014). The South is characterized by privately held timberlands and a vibrant softwood lumber market, and includes a healthy wood pellet industry (Ince, 2000; Qian and McDow, 2013; U.S. DOE, 2005; Wear and Murray, 2004) that can supply fuels to decentralized heating systems. One example is the Georgia Forestry Commission, which installed 16 pellet fueled biomass heating systems around the state (W2E, 2014). The Lake States area, like many other timber producing regions in the country, has seen decline in this sector over the last couple of decades, but still maintains a versatile forest products industry (e.g. pulp and paper, engineered wood products, and lumber mills) (Becker et al., 2009b) that could be leveraged to obtain locally sourced biomass fuels. In the Northeast, wood chips are the most prevalent biomass fuel source, but like other regions with growing urban areas alongside rural communities, can also obtain chipped whole trees as lands are cleared for infrastructure or housing expansion (Maker, 2004). South Appalachia also has an active forest products industry that currently supplies mill residues and chipped wood for institutional heating (USDA, 2007; W2E, 2014). In addition, all regions of the country can enjoy some level of wood chips from municipal waste, but this is not a common input for small decentralized boilers in institutions (Maker, 2004).

In addition to regional differences in geography and land cover affecting available feedstock; land ownership also plays a central role. Before the 1960s, a large portion of the softwood lumber production in the U.S. was on federal lands in the West and Rocky Mountain States, until mid-1990s when harvests began to decline, with a large drop off occurring after 1990

(Wear and Murray, 2004). A large portion of this decline took place on U.S. Forest Service lands (Anderson et al., 2013; Butler et al., 2014a; Butler et al., 2014b; Loeffler et al., 2014a; Stockmann et al., 2014a; Stockmann et al., 2014b; Stockmann et al., 2014c) in the wake of federal environmental policies enacted in the 1970s, such as the Endangered Species Act, which, in part protects habitats for endangered species. The Spotted Owl of the Northwest, which gained listing on the federal registry of endangered species in 1990, is a well-known case that gained national attentions for polarizing the environmental and logging communities (Wear and Murray, 2004). The passage of other policies such as the Multiple Use Sustained Yield Act of 1960 (MUSYA), the Wilderness Act of 1964,and the National Forest Management Act of 1976 (NFMA), also had a large effect on timber production on federal land as they required that other non-timber resources be considered when actively managing forested lands (Wear and Murray, 2004).

Other contributing factors to western wood production decline include changes in interregional harvest trends and international trade policy between the U.S. and Canada (Wear and Murray, 2004). High volumes of western harvests have historically come from the harvesting and processing of old growth forests, that were particularly common in the Pacific Northwest and the Alaskan panhandle (Mackovjak, 2010; Wear and Murray, 2004). As old growth forests were logged, the remaining stock was targeted for protection as these regions turned to more sustainable harvesting practices (Wear and Murray, 2004). At the same time the U.S. South and Canada began to increase production to fill the demand for wood products. The U.S. South timber industry is composed of mostly private land holders, with approximately 20% of the forested lands being held by private corporations, much of the remaining forestland held by private individuals and families, and very few lands held by the U.S. Forest Service (Loeffler et al., 2014b; Wear and Murray, 2004). Forest management in the South is increasingly turning to plantation forestry, where trees are grown in rows on relatively flat ground and harvested on 20 to 30 year cycles (Wear and Murray, 2004).

In addition to increasing harvests from the U.S. South, Canadian timber imports into U.S. markets also carry some influence on production levels and prices of the U.S. softwood lumber market. In 1986 the Department of Commerce’s International Trade Administration (ITA) ruled in favor of the U.S. softwood industry after they had complained that the Canadian government was subsidizing their lumber industry giving them a competitive advantage, which led to the “dumping” of Canadian softwood lumber in U.S. markets (Wear and Lee, 1993). The ITA ruling led to the 1986 Memorandum of Understanding (MOU) where it was agreed upon that the Canadian government would put an export tax of 15% on softwood lumber; an agreement that was made only after the U.S had threatened to impose a 15% import tax on all Canadian softwood lumber imported into the U.S. (Wear and Lee, 1993). In 1991, in accordance with previous amendments to the MOU the Canadian government dissolved the agreement since provinces had raised their stumpage prices until these equaled American prices (Wear and Lee, 1993). Currently 64% of Canadian softwood lumber is exported to foreign markets (NRC, 2014), in part, due to Canada's low population and high stock of forested lands. This is relevant to biomass heating because locally manufactured wood products, including sawn lumber, are closely tied to logging residues and sawmill residues that can be used as fuel. Residues from imported wood products are unlikely to be imported because of their relatively low value compared to sawn products and the relatively high cost of logistics.

In the context of the U.S. softwood lumber market, U.S. federal timber polices and the reduction of old growth forests have placed increased scrutiny on logging operation on federal lands in the U.S., while at the same time increased production for private land holders in the U.S. South and Canada (Wear and Murray, 2004). The effect of reduced timber harvesting on federal western lands has been negative on timber consumers as supply restrictions raised prices by roughly 15% in the U.S. softwood lumber market in the mid-1990s, while the net effect on the timber producers has been positive with regional winners and losers (Wear and Murray, 2004). The losses experienced by Western lumber producers as their regional stock of timber has become less obtainable, are far outweighed by the gains received by U.S. South and Canadian softwood lumber producers as they began to meet the demand at higher prices (Wear and Murray, 2004). In addition, within the U.S. softwood lumber industry there is evidence of leakage, as logging restrictions to preserve federal forested lands in the West and Rocky Mountain Region have increased logging and habitat degradation taking place in the U.S. South (Wear and Murray, 2004). Due to leakage and other discussions above, the availability and quality of woody biomass supply is dependent on local, active forest management strategies, which define the region's forest products industry and supply of forest based woody biomass resources. In general, patterns in timber production and use, especially for lumber, relate directly to the supply of biomass residues available for combustion heating, including institutional systems.

The Current State of Institutional Utilization

According to some technology developers, public officials and researchers, many small commercial or institutional facilities that are currently using natural gas or fuel oil as their primary heat source, and are located near forested lands would be ideal adopters of woody biomass heating systems due to lower heating costs and low supply needs (U.S. GAO, 2005). The heat output of small-scale thermal woody energy system ranges between one and ten million Btus, and generally these systems do not have electricity generating capacities (Maker, 2004). An example of a small-scale thermal woody energy system can be seen in Figure 2 (Maker, 2004). In most cases these can be equipped with automatic fuel handling and feeding systems to enhance their efficiency (Maker, 2004). It is common to maintain or install traditional fossil fuel boilers (e.g. natural gas or fuel oil) as a backup heating system that will be used when biomass fuels are temporarily exhausted, heating needs are too low or high, the automatic feeding system becomes clogged with a piece of oversized feedstock, or when the biomass boiler is shut down for general maintenance (Maker, 2004). Additionally, the installation of small scale woody biomass systems in the western U.S. is encouraged as a means to reduce hazardous fuels adjacent to at-risk communities, with these systems providing markets for biomass generated from fuel reduction treatments (Dykstra et al., 2008).

Some regions of the country are home to public and private institutions that have been receptive to policy incentives to use biomass heating systems. According to the Wood2Energy database these regions are most notably in Northeast states, the Lakes States, and Northwest states (Figure 3; W2E, 2014). For a complete list of counties currently containing a decentralized woody biomass heating system refer to Appendix A. Nationally, adopting regions of the country have on average higher heating degree days (higher space heating needs), lower road and population density (more rural), higher forest residue production (additional woody biomass resources), and larger portions of land owned by federal agencies. Many of these characteristics do not dominate in the central and southern regions of the country where institutional adoption of woody biomass is less prominent. On the other hand, Northeast states have many of the aforementioned characteristics, but lack large portions of federal lands and experience high energy prices. While the factors listed above hold major influence on the institutional adoption of biomass heating systems, some regions with these characteristics have not adopted biomass fuels as a viable heating option, possibly due to market barriers and limiting factors prevalent in regional and local markets.

Barriers and Limiting Factors to Biomass Use

Barriers holding back a vibrant nationwide biomass market come in many forms and are unique to each county and region of the nation, with western states facing the additional limiting factor of difficult geography and terrain (Skog et al., 2006; U.S. DOE, 2005). Some commonly cited barriers to local and regional biomass markets include:

- major differences in state RPS including funding levels, exemptions for publicly owned utilities, and the presence/lack of buyback programs (Wiser and Barbose, 2008);
- a lack of stable, long term supply chains (20 years or longer) both from private and federal lands (Galik, 2009; U.S. GAO, 2005);
- a lack of transmission line investment (Wiser and Barbose, 2008), which can limit both in-state and interstate transmission of renewable power;
- ecological concerns that too much carbon will be taken off of the landscape or natural lands will be converted to biomass crop lands (U.S. DOE, 2005; Fernando et al., 2011);

- fear of the negative effects that a vibrant woody biomass energy sector might have on other forest resource users, especially wood procurement for pulp and paper operations (Galik, 2009);
- a lack of local demand, processing infrastructure and utilization capacity (Fight et al., 2004; U.S. GAO, 2005; Keegan et al., 2006; Nielsen-Pincus et al., 2012);
- concerns that low valued woody biomass is too dispersed to be efficiently gathered to a central location (Dykstra et al., 2008; Nielsen-Pincus et al., 2012; Rummer, 2008);
- and high investment costs that are not recaptured until an extended period of time has passed (Paepe, et al., 2006).

While these barriers hinder the establishment and expansion of large scale biofuel or bioenergy facilities, many of these can be avoided at the institutional scale by carefully examining location theory and current literature for guidance when selecting the optimal facility size and location (Jenkins and Sutherland, 2013; Polagye et al., 2007; Rawstron, 1958; Renner 1947; Weber, 1929).

Theoretical Framework of Industry Location

Like previous adoption and location decision studies (Aguilar et al., 2012; Fortenbery et al., 2013), this study of institutional adoption of biomass as a primary fuel source has its foundation in Classic Location Theory and more modern Regional Science. Weber (1929), an early location theorist from Germany, identified seven cost factors driving industry location, four of which carry major influence and should be considered heavily when deciding on industry location. These are 1) cost of buildings, machines, and other fixed capital costs, 2) cost of securing materials, power and fuel, 3) the cost of labor, and (4) transportation costs (Weber, 1929). The other three are 5) land value, 6) interest rates, and 7) the rate of depreciation of fixed capital (Weber, 1929). The cost of materials, power and fuels, and transportation dictate regional location, and other variables affect sub-regional location (Weber, 1929; Renner, 1947). While Weber's seminal work on location theory is considered paramount, it received criticism for not taking into account the complex relationships within a government as large as that of the U.S. (Renner, 1947). This aspect is especially important when the government influences industry location through public policy.

In the years that followed, other economists chose to think of location theory in another light, identifying three principles of location restrictions (Rawstron, 1958; Renner, 1947): 1) physical restrictions, 2) economic restrictions, and 3) technical restrictions. Physical restrictions restrict industry locations to areas where input resources are available, depending highly on the resource pattern of occurrence and density (Rawstron, 1958; Renner, 1947). Physical restrictions in extractive industries like biomass removal can be captured in the law of *Location for Extraction Industries*, which states "The extractive industries are, and must continue to be located by the occurrence of their raw materials (Renner, 1947, p. 169)". Physical restrictions embody the first level of refinement, narrowing the field of possible locations very little in most cases. In the case of forest biomass use, this would restrict the field of choices to locations containing or close to wooded areas, or proximate to forestland classified as timberland in the terminology of forest management.

Industry locations are further narrowed by economic restrictions, which include cost structures of industry (labor, material, land, marketing, and capital) and spatial margins, in particular those of transportation costs (Rawstron, 1958). As transportation distance of biomass inputs increases, transportation costs may become too large for biomass boiler to be economically viable due to the low energy density and thermal conversion factor of biomass fuels compared to fossil fuels (BEC, 2014; Rummer, et al., 2005). In other words, biomass tends to be light, bulky and difficult to transport efficiently over long distances. In addition, new biomass facilities generally cannot tolerate high variable costs due to high installation costs (i.e. fixed capital costs), which result in an extended period before fixed costs are recaptured (Paepe, et al., 2006). Uncertainty in feedstock supply costs tend to drive up interest rates on debt and equity for such projects, and is often cited as a major barrier for financing (Galik, 2009; GAO, 2005). Financial incentives and cost share grants can reduce fixed costs, giving some flexibility to absorb higher fuel costs over the life of the project. Additional financial incentives and cost share grants can incentivize biomass market demand leading to increased mass-production and cost reductions as the market matures (Paepe et al., 2006), but long-term fuel supply agreements are rare (Galik, 2009; U.S. GAO, 2005).

The third principle is technical restrictions. Technical restrictions include both the method of production (biomass combustion boiler) and the organization of administration (e.g. biomass supply chain and boiler operators), where in the limiting case technical perfection demands location perfection (Rawstron, 1958). In other words, if technology advancements are less prominent and less costly, less scrutiny can be given to the location-specific factors of an industry. On the other hand if technical advancements are common and require large capital investment, location specific factors (i.e. physical and economic restrictions) could have high influence on industry location. In the case of this study advances in biomass combustion are prominent when compared to the average lifespan of an institutional heating system and installation can be very costly. For these reasons increased scrutiny should be applied to potential adoption locations to make sure that locations satisfy the first two restrictive principles before a biomass combustion boiler is installed.

The emergence of Regional Science has given new breadth to the classification of factors that determine the location of industry. As suggested by the seminal work of Lloyd and Dicken (1977), Regional Science divides industry location factors based on a firm's decision power where variables are distinguished between those that are in control of the firm, those defined by the firm's environment, or those that are highly dependent on location, making these fixed in the short run (Van Dijk and Pellenbarg, 1999). Therefore factors driving regional location are divided into three categories: 1) internal, 2) external and 3) location specific factors. Internal factors are those that are specific to a firm or institution and include production technology, management structure, ownership, turnover rates, employment and profits (Van Dijk and Pellenbarg, 1999). In the context of this study internal factors also include intra-county mechanisms to determine the number of institutions needed. External factors are those that are not in direct control of the firm, but are external conditions and changes that affect the firm; including government policies and regulations, regional economic structures, and technical advances (Van Dijk and Pellenbarg, 1999), as well as supporting factors like climate conditions and soil quality (Renner, 1947). Location specific factors are absolute and relative characteristics of a fixed geographic location such as access to inputs for production and distance to supplies and end markets, as well as the presence of support services (Nicholls et al., 2006, Van Dijk and Pellenbarg, 1999).

In addition to using Classic Location Theory and Regional Science to help guide industry location, Renner (1947) makes a powerful argument in favor of decentralization of mature industries. When an industry is in its infancy, it tends to follow patterns that are strongly dictated by geographic patterns. As an industry matures, natural selection and specialization begin to take hold, driving the remaining firms to seek locations that are ideally suited for production. As a result, pseudo-homogenous industries will self-segregate and concentrate, in turn driving urbanization and further industry concentration. When an industry has reached post-maturity, decentralization becomes an attractive means to avoid the problems that are caused in part by industry maturity and urbanization. These problems include urban congestion, social problems, high urban rent, increased taxes and regulations, increased insurance rates, and the incapacity to maintain full employment in the case of a recession (Renner, 1947). In the context of space heating centralized fuel distribution systems have developed in urban areas to efficiently meet the heating needs of the local community by providing heating fuels in the form of natural gas, propane, or fuel oil, as well as electricity delivered by the utility grid. While centralized distribution systems of carbon-based fuels can efficiently provide space heating in urban communities, rural communities lack the infrastructure or demand to support these systems. An alternative is small biomass heating systems that facilitate the decentralization of the heating fuels industry, which in turn supports industries located in rural communities.

Using Classic Location Theory, Regional Science and the theory of decentralized industries for guidance, the current technology of small combined heat and power (CHP) systems have been shown to be economically feasible providing appropriate market conditions, deployment circumstances and driving factors are in place (Wood and Rowley, 2011; Salomon et al., 2011). Similar studies have also examined CO_2 emission reductions achieved when retrofitting small scale fossil-fuel combined heat and power systems (CHP) to incorporate woody biomass (Pavlas et al., 2006), the optimization of incorporating biomass into large scale fossil-fuel CHP plants (Tous et al., 2011), as well as the factors driving the co-firing of coal and woody biomass in U.S. Northeast, Lake States, and the eastern Midwest regions (Aguilar et al., 2012). Less work has been done to identify the key factors driving the institutional use of biomass in small decentralized biomass heating systems, a goal of this analysis.

The Purpose of this Study

Diverse active forest management in the U.S. supplies a timber products industry that produces an abundant amount of woody biomass resources that could be used in decentralized biomass heating systems (Greg and Smith, 2010; Rummer et al., 2005; U.S. DOE, 2011). Also, due to a century of successful wildfire suppression of low intensity fires many federal lands have excessive fuel loads, which increase their risk of experiencing high intensity fires that can alter the landscape (Polagye et al., 2007; Raffa et al., 2008; Rummer et al., 2005). Biomass flows as the result of active forest management, the timber products industry, and excessive fuel loads removed under the NFP can serve as a decentralized fuel stock for our national institutions. The purpose of this study is to expand the limited knowledge of economic factors that individual institutions appear to take into consideration when deciding whether or not to utilize biomass supply flows and adopt a woody biomass heating system.

The goal is to inform the adoption rate of decentralized woody biomass heating systems by institutions in the U.S. using a ZINB regression analysis to identify internal, external, and location specific factors that are favorable to adoption. In addition, policy efficacy with respect to decentralized biomass heating systems is analyzed and regression results are used to develop an expansion map that highlights areas in the U.S. that have favorable conditions for woody biomass heating. Rather than emphasizing the selection of new industry location alone, our study also focuses on identifying factors that appear to drive the adoption of woody biomass boilers by institutions and thus understanding factors favorable to facility siting. Knowing what factors are favorable to facility siting of woody biomass heating systems will provide information that institutions can use in their consideration of alternative heating systems. The successful expansion of the institutional biomass heating market will reduce greenhouse gas emissions into our atmosphere, and empower local leaders to consider installing renewable heating technologies when the time comes to upgrade their current heating system. In turn, receptive owners of small local businesses can look to adopting institutions for inspiration and guidance on how they too can reduce global greenhouse gas emissions while meeting their heating needs with modern innovative woody biomass heating systems. Conversely, knowing factors favorable to facility siting will help determine which institutions are not ideal targets of government programs that encourage woody biomass use. A special emphasis is given to county and state level factors, such as economic conditions, land ownership patterns and public policies favorable toward biomass utilization.

Methods and Data

Methods

This study identifies the key factors driving the institutional use of biomass in small decentralized biomass heating systems by using a zero-inflated negative binomial (ZINB) model. A ZINB statistical model is used to predict the number of events, where an event is defined as an institution using a woody biomass heating system to fill heating needs. Institutions are defined as primary and secondary educational facilities (both private and public), hospitals, government buildings, prisons, military bases, and community gathering facilities, such as community halls, recreation centers, and other public buildings. The scope of the study is the U.S. with 3,142 counties or county equivalents serving as the observational units, excluding Washington D.C. Counties were chosen as observational units because these are the smallest geographic units with full data coverage for the study area. Much of the government data used in this analysis is reported on a county basis. The count or number of institutions using woody biomass within each county is the response variable.

Count data theoretically follow a Poisson distribution where the mean equals the variance (Hu et al., 2011). However in practice this assumption is often violated due to overdispersion where count data shows greater variability than predicted by the Poisson distribution (Zuur et al., 2009). Among other things, overdispersion can be driven by unobserved heterogeneity (Phang and Loh, 2014) resulting in an excessive number of zeros and a variance that far exceeds the mean. In the context of institutions using biomass boilers to produce heat, excessive zero counts can be the result of restrictions on biomass extraction due to *the law of Location for Extraction Industries*, as discussed earlier. Count of institutional biomass use has a mean of 0.1276 and a variance of 0.4563 giving evidence of overdispersion. A visual representation of overdispersion can be seen in long right skewed histogram tails (Figure 4). Should overdispersion occur in nonnegative count data, theory suggests that the Negative Binomial (NB) distribution offers superior fit compared to the Poisson (Hu et al., 2011).

In addition to considering how excessive zero counts affect the mean and variance, the origin of zero counts must also be considered (Hu et al., 2011). If zeros in count data are believed to come from a single origin in the sample, representing true zero counts, then Zero Altered (Hurdle) models would be appropriate (Hu et al., 2011; Zuur et al., 2009). On the other hand, if zero counts are believed to come from two sources; with excess zeros due to structural barriers and true zero counts due to sampling chance, then Zero Inflated (ZI) models should be considered because these allow for structural zeros to be modeled independently[6] (Hu et al., 2011; Phang and Loh, 2014). Ignoring zero inflation is not advised as it may result in biased standard errors (Zuur et al., 2009). Additionally, in situations where zero inflation is evident, there is a high chance of overdispersion, which makes the ZINB distribution an attractive alternative to the Zero Inflated Poisson (ZIP) (Hu et al., 2011).

In the context of this study, zero counts have two origins and should be modeled independently of one another; the first being structural and second being true zeros in the sample. Structural zeros result from counties with structural constraints such as a lack of heating needs or resources and are predicted using a ZI model (logistic model). Sample zeros originate from counties that apparently are suitable for woody biomass use but have not adopted biomass technologies and follow a NB distribution (count model). For the reasons outlined above theory suggests that for this study a ZINB mixed model be used to estimate the count of institutions using biomass.

In the ZINB model the count of institutions using woody biomass is Y_i, where $i = 1,.,.,3142$ has a probability mass function given by:

$$\Pr(Y_i = y_i) = \begin{cases} p_i + (1-p_i)\left(\dfrac{\phi}{\mu_i+\phi}\right)^{\phi}, & y_i = 0, \\ (1-p_i)\dfrac{\Gamma(\phi+y_i)}{\Gamma(y_i+1)\Gamma(\phi)}\left(\dfrac{\mu_i}{\mu_i+\phi}\right)^{y_i}\left(\dfrac{\phi}{\mu_i+\phi}\right)^{\phi}, & y_i = 1,2,.,., \end{cases}$$

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[6] A ZINB example and current model analogous follows: Suppose we are interested in the number of fish caught while camping with your family by a lake. Families that do not go fishing cannot catch fish (structural zeros) and should be modeled independently of families that go fishing, but do not catch any fish (true sample zeros) (IDRE, 2014a). If only families who went fishing were included in the sample a ZANB model would be appropriate, otherwise a ZINB model is preferred. In the context of this study, counties that do not need space heating or do not have supplies of woody biomass (structural zeros) should be modeled independently of counties who do need space heat and have access to woody biomass, but choose not to have biomass heating in their institutions (true sample zeros). Therefore a ZINB model is the preferred model in the context of this study.

where $\Pr(Y_i = y_i)$ is the probability of county i containing y institutions using woody biomass, $0 \le p_i \le 1$, $\mu_i \ge 0$, ϕ^{-1} is the dispersion parameter with $\phi > 0$, and $\Gamma(\cdot)$ is the gamma function (Garay et al., 2011). The mean and the variance are $E(Y_i) = (1 - p_i)\mu_i$, and $Var(Y_i) = (1 - p_i)\mu_i(1 + \mu_i\phi^{-1} + p_i\mu_i)$, respectively. When p_i =0, the dependent variable Y_i has a NB distribution parameters with the mean μ_i and dispersion parameter ϕ (i.e. $Y_i \sim NB(\mu_i, \phi)$) (Garay et al., 2011).

In application the parameters μ_i and p_i depend on vectors of independent variables z_i and x_i, respectively, resulting in the following models (Garay et al., 2011):

$$\log\left(\frac{p_i}{1 - p_i}\right) = z_i^T \gamma \quad \text{and} \quad \log(\mu_i) = x_i^T \beta, \qquad i = 1.,.,.,n,$$

where $\gamma = (\gamma_1,.,.,\gamma_q)^T$ and $\beta = (\beta_1,.,.,\beta_p)^T$ are unknown parameters for the ZI and NB models, respectively (Garay et al., 2011).

In practical terms the ZINB modeling approach can be used to model data that is overdispersed, due to high zero counts that are from two distinct sources. Data of this nature is common in the medical field where many of the observed values are zero due to an absence of a particular disease or perhaps pregnancy, and in wildlife biology where the presence/absence of a particular species is of interest.

Data

The 3,142 observational units are counties or county equivalents and were determined to be the smallest, practical units with complete datasets for the U.S. Counties are assumed to be standardized units based on border determinants such as geographic, infrastructure, and societal barriers. The response variable Y_i (county count of institutions using biomass in decentralized heating systems) was obtained from the Wood2Energy database sponsored by the Endowment for Forestry and Communities Incorporated, Biomass Thermal Energy Council, Biomass Power Association and the Pellet Fuels Institute (W2E, 2014). Of the 3,142 observational units there are 225 non-zero observations (Figure 3). Washington D.C. was removed from the analysis because the number of policies in support of biomass use for the county equivalent is unknown.

Using Classic Location Theory and Regional Science as a guide, a vector of candidate a priori independent variables was gathered and considered for inclusion. The ZI portions of the models have three inputs that have theoretical ground to be associated with structural zero counts. The first 'Heating Degree Days' was obtained from the National Oceanic and Atmospheric Administration (NOAA) and is calculated using a base of 65 degrees Fahrenheit (NOAA, 2014). For every degree below 65 degrees on any given day the county receives a heating degree day equal to the difference between 65 degrees and the average temperature. For example if a county has an average temperature of 45 degrees Fahrenheit on a given day it will receive 20 heating degree days for that day. For a day that averaged a temperature above 65 degrees that day receives a heating degree day of zero. The inclusion of heating degree days was to control for some of the variability in heating requirement due to differences in local climates. As heating degree days increase the expected count of institutions using biomass is expected to increase. The second variable 'Population Density' is measured in population per 1,000,000 square meters (m^2) and was obtained from the U.S. Census Bureau (2013). Population density was included to control for institutional needs of the county. More populous counties are expected to have higher need for institutional heating. The third and final variable in the ZI model, 'Forest Residues', includes logging residues and other removable forest management byproducts. Forest residue was obtained from timber product output data compiled by the U.S. Forest Service (USDA, 2007) and includes both logging residues[7] and other removals[8] (Milbrandt, 2005). Forest residues was included as a proxy for woody biomass availability through active forest management. As forest residues increase, biomass fuel market conditions improve, which increases the expected count of institutions using woody biomass as a fuel source. Other variables considered to represent woody biomass availability were primary mill, secondary mill, and urban wood residues. Forest residues were chosen over primary mill residues because primary mill residues are usually located near the source of forest residues. Forest residues were also selected for inclusion over secondary mill residues and urban wood residues because these are heavily influenced by the local housing market through construction inputs and tree trimming maintenance rather than local forest management. In addition, prior studies support the inclusion of logging residues over these other options (Leefers, 2011).

The NB model also included 'Heating Degree Days' and 'Forest Residues' as both variables not only affect the odds of a county having one institution using a biomass heating system, but also the total number of institutions using a biomass heating system. In addition to these, other variables were also included in the NB model. Commercial 'Natural Gas Price' per 1,000 cubic feet (ft^3) was obtained from the U.S. Energy Information Administration (U.S. EIA, 2013), and

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[7] "Unused portions of trees cut, or killed by logging, and left in the woods" (Milbrandt, 2005, p. 18).

[8] "Trees cut or otherwise killed by cultural operations (e.g. pre-commercial thinning, weeding, etc.) or land clearings and forest uses that are not directly associated with round wood product harvests" (Milbrandt, 2005, p. 18).

serves as a proxy for competing energy prices. As fossil-based energy prices increase, the expected count of institutions that will turn to biomass as an alternative heating fuel also increases. Other competing fossil-based energy prices that were considered for inclusion over commercial natural gas prices were propane and heating oil. Propane prices were not selected for inclusion because these could not be effectively allocated at the county level, but only at the regional scale due to proprietary price data restrictions. Heating oil prices were not included because the price data are incomplete.

Owner occupied median 'House Value' measured in dollars (thousands) was obtained from the U.S. Census Bureau (2013) and serves as a proxy for county affluence levels. As the affluence level increases, so does the demand for a cleaner environment and renewable energy, which in turn increases the expected number of institutions using a woody biomass heating system.[9] More affluent communities are also more likely to have the financial resources to install a new biomass heating system. However, it is important to note that affluent communities may not view biomass combustion as an attractive renewable energy. A recent study by Yoo and Ready (2014) carried out a choice experiment in Pennsylvania and found that among other renewable energy options, biomass combustion was viewed as unfavorable across the population.

'Biomass Planned' measured in millions of treated m^2 was obtained from the National Fire Plan Operating and Reporting System (NFPORS, 2014) and serves as a proxy for land treatments that are likely to produce available biomass from reducing fuel loads in accordance with the National Fire Plan (NFP). This variable includes treated lands owned by Federal and State governments, as well as adjacent private lands and lands owned by private forestry programs. As the volume of treated acres increases, the expected count of institutions in a county using a biomass heating systems also increases.

The proportion of 'Federal Land' in each county was calculated using Environmental Systems Research Institute's Geographic Information Systems (ESRI GIS) software with data obtained from a joint database established by a cooperative group between ESRI, the National Atlas, and the U.S. Geological Survey (ESRI, National Atlas, USGS; 2005, 2012). Proportion of 'Federal Land' is further divided into individual land holding agencies in model extensions. The inclusion of proportion of federal land was to represent large portions of land ownership and federal policies.

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[9] Another variable that was considered for inclusion was population change as a proxy for county growth. If a counties population is increasing its institutions are more likely to invest in new heating systems, while counties with decreasing populations are more likely to continue using current heating systems. However, it was determined that population change is reflected in the median house value of a county when holding all other variables constant. An area with a decreasing population has a housing surplus that drives down prices.

State ‘Total Policies’ encouraging the use of woody biomass and renewable energy in general was obtained from a prior publication by Becker et al. (2011b). ‘Total Policies’ is further divided into policy types in a model extension (Table 1). The inclusion of total polices was to control for the political atmosphere and financial incentives. As the number of policies encouraging the use of biomass increases, so do the expected count of institutions in a county using a biomass heating system. Of the included variables, ‘Total Policies’ is the most likely endogenous independent variable, violating the exogeneity assumption. In this context, if a state has more woody biomass heating systems it may be more likely to adopt woody biomass policies leading to reverse causality. Endogeneity could materializes for two reasons, 1) biomass policies were passed to support existing decentralized biomass plants, or 2) woody biomass policies are only passed in states with woody biomass resources (Hitaj, 2013). The first source of endogeneity is unlikely because decentralized heating systems are rare in the U.S and are largely not the focus of policy makers due to their low consumption of woody biomass, which displaces a limited quantity of traditional fossil fuel. The second source of endogeneity is not a concern due to the wide breadth of policies used, which target renewable energy in general rather than being focused solely on woody biomass use. In addition, at a bare minimum one should expect moderate to high correlation in the number of policies and the number of institutions using a woody biomass heating system, which is only 0.03 for ‘Total Policies’ and among policy types is at most 0.11 for ‘Cost Share/Grant’ policies (Table 4).

Another variable included was ‘Population’ measured in hundreds of thousands. Population was obtained from the U.S. Census Bureau (2013), and was included as a proxy for the number of institutions in a county. As the population rises, so does the number of institutions. Theoretically an increase in the number of institutions in a county would also increase the number of institutions using biomass heating systems, holding all other variables constant.

The variable ‘Road Density’, which includes both primary and secondary highways was obtained from the U.S. Census Bureau (2013) and was included as a proxy for access, specifically in biomass transportation logistics. As road density increases so does the access to woody biomass resources, as well as the infrastructure available to transport these to a central location. Other variables that were considered for inclusion as a proxy for infrastructure were railroad density and the density of navigable waterways. Neither variable was selected because both are highly correlated with road density, but fail to adequately cover many regions of the U.S.

‘Port Capacity’ of 150 principal ports in the U.S. was obtained from the U.S. Army Corps of Engineers (U.S. Army Corps, 2014). Port capacity is measured in short tons (hundred thousand) and was calculated as an average from 2008 to 2012 where each principal port capacity total for the five year span was divided by the number of years it was considered a principal port, which resulted in 164 principal ports attributed to 156 counties. Principal port capacity is a proxy for waterborne commerce. As waterborne commerce increases, it may increase commerce associated with woody biomass pellet and chip production, which may increase the count of institutions using a woody biomass heating system. On the other hand as waterborne commerce increases it may increase the level of wood pellets and chips being exported to the EU or other countries; this may have little or no effect on small decentralized heating systems in the U.S.

Finally, ‘County Area’ was obtained from the U.S. Census Bureau and is measured in billions of m^2. County area was included to control for the quantity of land in the county domain, as well as to determine the effects of county area on the adoption of institutional biomass heating systems. As a county increases in area it is expected to contain more woody biomass resources and institutions, holding all other variables constant.

According to Regional Science each variable described above can be placed into one of three factors based on decision power. Factors that an institution or county has complete control over are internal (Van Dijk and Pellenbarg, 1999). In the context of this study, an internal variable refers to both the average inter-institutional characteristics of institutions who have adopted woody biomass heating systems, and intra-county mechanisms to determine how many institutions are needed given there is a need for a single institution. Internal factors include population density as a proxy for the need for a single institution and population as a proxy for the number institutions needed. These variables, in effect, control for a county’s need to establish new institutions through the process of elections and government management. Average inter-institutional characteristics were not available and have not been included. Ideal inter-institutional characteristics to include if available are average heating space of institutions, the fuel source used by both the old fossil-fuel system and the new woody biomass system, and the average number of employees responsible for boiler operation and maintenance.[10] External factors are those that are not in direct control of the institutions or the government processes to establish new institutions, but by which these are affected by external conditions and changes (Renner, 1947; Van Dijk and Pellenbarg, 1999). These include ‘Heating Degree Days’, commercial ‘Natural Gas Price’, and ‘Total Policies’. Location specific factors are absolute and relative characteristics of a fixed geographic location (Nicholls et al., 2006; Van Dijk and Pellenbarg, 1999), in this case the county or county equivalent. They include ‘Forest Residues’, median ‘House Value’, available ‘Biomass Planned’ under the NFP, proportion of ‘Federal Land’, ‘Road Density’, ‘Port Capacity’, and ‘County Area’ all of which are highly dependent on geographic characteristics of a county.

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[10] Facility level analysis was considered, but abandoned due to inadequate data.

Regional indicator variables from Becker et al. (2011b) (Figure 1), and the latitude and longitude of the geographic center of each county are included to control for geographic location. A list of included variables along with descriptions, units, and sources can be found in Table 2. Descriptive statistics for the response and explanatory variables can be found in Table 3, and a correlation matrix in Table 4.

Model Diagnostics

An important step in all data modeling is checking both the model assumptions as well as model performance compared to alternative modeling techniques. Competing models include the un-nested Negative Binomial (NB) model for overdispersed count data that are not zero inflated, the nested Poisson model for count data that are not overdispersed nor zero inflated, and the Zero Inflated Poisson (ZIP) for zero inflated count data that are not overdispersed. Recall ZINB models are designed for data that are both overdispersed and zero inflated. Model diagnostics were carried out using STATA 12.1 (StataCorp, 2011).

As a first step a t-test is performed on the dispersion parameter alpha (α) to test the null hypothesis that α is equal to zero, which would indicate that overdispersion in the response is not caused by unobserved heterogeneity (Sari, 2009). The dispersion parameters, α, and p-values are presented in Table 5. For all three models the alpha parameter is significant at the 1% level leading to a rejection of the null hypothesis, which indicates that unobserved heterogeneity is causing overdispersion in the response that in turn violates the Poisson assumption of a variance that equals the mean (Sari, 2009). This violation of the Poisson distribution points to the NB distribution being favored over the Poisson.

With known overdispersion being present in the data the next step is to see if it is the result of excessive zero counts in the response variable, also known as zero inflation (Sari, 2009). This can be accomplished by using the Vuong test to compare un-nested models. In this case I am comparing the ZINB model to the NB model, with the null hypothesis that both models work equally well. The test results depend on model order. If the test statistic (V) is positive and statistically significant the first model is preferred, and if V is negative and statistically significant the second model is preferred (Sari, 2009). Vuong test statistics (V) and p-values for all three models can be found in Table 6. All three models have a V that is positive and statistically significant at the 1% level, leading to the conclusion that the ZINB modeling technique is preferred over that of the NB, due to overdispersion as a result of excessive zero counts in the response.

A final step in model assessment is to confirm that the ZINB model is superior in modeling zero inflation in the response than the ZIP. This final step is somewhat repetitive to the first step as it too examines the α parameter. Although, instead of using t-statistics a likelihood ratio test is carried out on the main ZINB model and the ZIP nested model with the null hypothesis the nested model is preferred (Sari, 2009). The alternative hypothesis is that the ZINB model is preferred (Sari, 2009). Z-scores and p-values for all three models can be found on Table 6. With large z-scores that are statistically significant at the 1% level I reject the null hypothesis in favor of using the ZINB modeling technique.

In addition to formal statistical tests, the percent of counties correctly predicted was calculated (Table 5), and a comparison of actual and predicted counts was prepared (Table 7). The percent of counties correctly predicted to contain their actual count of woody biomass heating systems within ± 0.49 for Models 1, 2, and 3 are 91.41%, 91.53%, and 91.82%, respectively (Table 5). Furthermore, the percentage of counties that are predicted to have a zero count in Model 1, 2, and 3 are 92.61%, 91.93%, and 90.71%, respectively, which are very close to the actual percentage of 92.84% (Table 7). Table 7 displays the actual percentage of counties and institution counts with their predicted counterparts for all three models up to a count of five institutions. The highest difference for all three models occurs for an institution count of one.

Results

Three models were estimated using STATA 12.1 (StataCorp, 2011); with logical expansions of federal land management in Model 2 and policy type in Model 3 (Table 5). The base model (Model 1) estimates the number of institutions using biomass heating systems within a county's borders with model parsimony in mind. Federal land management was split by agency in Model 2 to assess how an agency's mandates affect their ability to foster biomass production for decentralized heating systems. Model 3 splits biomass energy policies by type to determine which policy instruments are associated with increased number of woody biomass heated institutions. The remainder of the results section is structured as follows: 1) an interpretation of significant results in the base model (Model 1) along with detailed explanation of odds ratios (OR) and incidence rate ratios (IRR), 2) a discussion of model extensions, Model 2 and Model 3, with interpretations of significant results and deviations from the base model, 3) selection of the preferred model using likelihood ratio test of nested models, 4) followed by in-sample model predictions based on the preferred model.

Model 1

Looking at Model 1 in Table 5 some general conclusions and model interpretations can be drawn. When predicting the odds of structural zeros (where success is not using woody biomass as a fuel source) in the ZI portion of the model, all of the slope coefficients are negative and statistically significant. In other words, higher heating degree days, population density, and forest residues decrease the odds of a county being a structural zero. Referring to the NB portion of the model, which predicts the likelihood of the number of institutions using biomass, statistically significant coefficients that are positive include 'Heating Degree Days', commercial 'Natural Gas Prices', median 'House Value', available 'Biomass Planned' from lands treated under the National Fire Plan, and the proportion of 'Federal Lands'. That is to say an increase in each is positively associated with an increased likelihood of the number of institutions. Conversely, due to their negative coefficients an increase in 'Road Density' and 'Port Capacity' decreases the number of institutions using woody biomass.

'Heating Degree Days' appears in both model steps, and is a good variable to illustrate correct interpretation of model parameters. Like other binary models the ZI portion of this model gives coefficients (β) that are in terms of log odds[11], and are easiest interpreted when transformed to odds ratios (ORs) or marginal effects (ME). For a discussion on ME refer to Appendix B. Transforming coefficients to ORs is accomplished by taking the exponential of the coefficients. In this case I have negative coefficients that result in ORs that are less than one, which cannot be interpreted in a straightforward manner. Looking at Table 5, Model 1 heating degree days has an OR of 0.813, which indicates that the addition of 1,000 heating degree days is associated with a 0.813 factor decrease in the odds that the county does not contain an institution using biomass. An alternative is to define success as having an institution that uses woody biomass. This would result in an inverse odds ratio to those displayed in the ZI portion of the models in Table 5.

With this in mind, each addition of 1,000 heating degree days is associated with a 1.23 (=1/0.813) factor increase in the odds that the county contains an institution using woody biomass, while the addition of 2,000 heating degree days (just under 1 standard deviation) increased the odds by a factor of 1.51 (=1/(Exp(-0.207*2))), holding all other variables constant. Likewise the addition of one person per 1,000,000 m^2 ('Population Density') is associated with a 1.04 (=1/0.957) factor increase in the odds that the county contains an institution using woody biomass, while the addition of 6.7 persons per 1,000,000 m^2 (a standard deviation) is associated with a 1.34 (=1/(Exp(-0.044*6.7))) factor increase. Finally, the addition of 10 million m^3 of

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[11] β=logarithmic (odds of success/odds of failure)=log(($p_{success}$/(1- $p_{success}$)) / ($p_{failure}$/(1- $p_{failure}$))), where $p_{success}$ is the probability of a structural 0, and $p_{failure}$ is the probability of not being a structural zero (IDRE, 2014d).

‘Forest Residue’ in a county is associated with a 7.52 (=1/0.133) factor increase in the odds of containing an institution using woody biomass as a primary heat source. While the forest residue parameter is statistically significant and vital to modeling structural zeros, its interpretation has limited practical and policy implications, in part because in this context most current and future users of woody biomass as a fuel source must be located near a biomass supply, of which institutions use very little as a proportion of total stocks and flows attributed to forest management activities that produce biomass.

While the ZI portion of the model is most easily interpreted through OR values, count models like the NB portion of the ZINB model gives coefficients (β) that are in terms of the log difference between expected counts (μ)[12] and are most easily interpreted as IRRs. Transformation of the parameters to IRRs is accomplished by taking the exponential of the coefficients. Unlike odds ratios discussed above, which represent linear relationships between the response variables and the coefficients (IDRE, 2014b), IRRs represent exponential growth (Hilbe, 2008), where the interpretation remains constant regardless of the starting point.

Looking at ‘Heating Degree Days’ in Model 1, an IRR of 1.210 indicates that each addition of 1,000 heating degree days is associated with a 1.21 factor increase in the likely count of institutions using biomass as a heating fuel, holding all other variables constant at their mean values (Figure 5). In other words, areas of the country with 6,000 heating degree days like counties in Nevada, Colorado, Nebraska, Illinois, Massachusetts, and Rhode Island are expected to have a count of institutions using woody biomass heating systems that is 1.21 factors higher than counties with the approximate mean value of heating degree days (5,000) in Indiana, Virginia, and Kansas. Likewise, counties with 5,000 heating degree days are expected to have a 1.21 factor increase in the number of institutions using biomass heating systems when compared to counties with 4,000 heating degree days, which are in New Mexico, Oklahoma, Arkansas, Tennessee, Missouri, and Maryland. For the average county an increase of 2,000 heating degree days (just under 1 standard deviation) is associated with a 1.46 ($=1.210^2$)[13] factor increase in the likely count of institutions using biomass. To put this in context the average number of institutions using biomass heating systems per county is 0.13 institutions, which is curtailed due to zero inflation. The mean heating degree days for counties currently using biomass heating systems is 6,783 (Ingham County, Michigan; Franklin County, Massachusetts; McKean, Crawford, and Warren Counties, Pennsylvania), with a minimum of 1,683 (McIntosh, Liberty, and Long Counties, Georgia) and a maximum of 14,738 (Yukon-Koyukuk Census Area, Alaska).

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[12] $\beta=\log(\mu_{x+1})-\log(\mu_x)$, where x represents the dependent variable and +1 represents a one unit change in x (IDRE, 2014c).

[13] A multiunit change interpretation of the IRR accomplished by calculating $\exp(\beta\Delta X)$, where β is the coefficient and ΔX represents a multiunit change in variables X (Hilbe, 2008)

Continuing with the NB portion of the model an increase of commercial 'Natural Gas Prices' of one dollar per 1,000 ft^3 in an average county is associated with a 1.30 factor increase in the expected number of institutions using biomass (Figure 6). The average commercial natural gas price in the U.S. is roughly \$10.43 per 1,000 ft^3. A natural gas price increase of roughly one standard deviation to \$12.43 per 1,000 ft^3, which resembles some areas in the Northeast, results in an increase of expected institutions just over a factor of 1.70 ($=(1.304^2-1)*100$), giving strong evidence of an economic impact. A price of \$14.43 per 1,000 ft^3, which is at the higher end for commercial natural gas prices in the continental U.S., results in a 2.89 ($=1.304^4$) factor increase in the expected number of institutions using biomass as a fuel source.

A standard deviation increase in median 'House Value' of \$80,000 increases the expected number of institutions by a factor of nearly 1.38 ($=1.004^{80}$) (Figure 7). As affluence levels in a county rise, there is strong evidence that the likely count of institutions using biomass will also increase.

An increase in available 'Biomass Planned' as a result of forest treatments on one million m^2 of land under the NFP increases the expected number of institutions by a factor of 1.01 (Figure 8). A standard deviation increase of 12.8 million m^2 of treated lands increases the expected number of institutions using biomass heating systems by a factor of 1.12 ($=1.009^{12.8}$), giving strong evidence that the NFP has had an economic impact on woody biomass use.

The addition of one standard deviation in the area of 'Federal Land' as a proportion of county land base (roughly 0.24) is associated with just under a 1.22 ($=2.275^{0.24}$) factor increase in the expected count of institutions using biomass, holding all other variables constant (Figure 9). This effect, while holding economic and statistical significance, has narrow implication for state and local policy in part due to the scarce nature of land and the relatively negligible control local governments have in increasing a county's area of federal lands. However, the significance of the proportion of federal lands does suggest that the management of federal lands through the implementation of federal policy is an important dimension when considering the adoption of woody biomass heating systems.

Conversely, the addition of one standard deviation of meters (m) of roadway per 1,000 m^2 of county area ('Road Density') changes the expected number of institutions using a woody biomass heating system by a factor of 0.81 ($=0.340^{0.20}$), all other variables held constant. Likewise, the addition of 9,300 short tons in 'Port Capacity' changes the expected number of institutions using woody biomass for the average county by a factor of 0.86 ($=0.984^{9.3}$). Both parameters hold suggestive economic significance. As road density or port capacity increases the likely count of institutions decreases. This may be because more urbanized areas are characterized by high road and port density and are less likely adopters than rural areas close to forest biomass.

Some variables hypothesized to be significant were not. One telling statistically insignificant result is the coefficient of 'Forest Residue' in the NB portion of the model. While the availability of forest residues is an important aspect in the ZI model step this does not hold for the NB model step. This may be because available forest residues are essential for institutions installing a single woody biomass heating system, but the quantity of forest residues needed to run many heating systems in the county may be much lower than what is available.

Controls for geographic locations were also largely significant. 'Latitude' and 'Longitude' of the geographic center of each county were both positive and statistically significant at the 1% level. As a county's location is further north and/or west the expected count of institutions using biomass increases. In addition compared to the base case of the South Appalachia Region (Figure 1) all other regions are expected to have more institutions with biomass heating systems. Controls for geographic location were included to reduce potential spatial autocorrelation and autoregression in the model, and their inclusion had very little effect on the model coefficients and their significance. More advanced spatial models were not pursued because there is recent empirical evidence that in the presence of properly modeled excess zeros the additional modeling of spatial structures results in very little gained. Fortenbery et al. (2013) and Musenge et al. (2011) employ models equipped to handle zero inflation and overdispersion (tobit and logit, and ZIP and ZINB models, respectively), and present stable non-spatial models that have coefficients with nearly identical significance to their spatial counterparts. Nevertheless advantages of modeling the spatial structure include removing potential bias from coefficient estimates and efficiency gains in standard error calculations (LeSage and Pace, 2009; Musenge et al. 2011).

In addition to variable selection described above, the exclusion of observations in Alaska and Hawaii was investigated to check for influential outlying observations and little effect on the models was found. It was concluded that the selected models described below were robust to the exclusion of observations in Alaska and Hawaii. Also, the sample size was restricted based on forest residue availability in two scenarios (forest residues=0; forest residues<0.1). Proper modeling techniques (ZINB and NB respectfully) revealed stable results with the exception of lost significance of house value when forest residue <.01. Upon examination this was the result of dropping adopting counties with high house value and low levels of forest residues. Furthermore, both model extensions described below did not significantly affect the variables of interest like commercial natural gas prices, proportion of FS land, biomass from NFP treatments, and policy effects.

Model 2 – Model Extension

To further investigate the impact that federal land holdings have when predicting the likely number of institutions using woody biomass heating systems Model 1 was expanded to split apart federal land ownership by agency (Table 5, Model 2). The 'NPS', 'FWS', 'BOR', 'BLM', and 'BIA' lands have negative insignificant associations with the expected count of institutions, with that of the FWS being statistically significant and NPS holding suggestive influence. Conversely the 'FS' and 'DOD' lands have positive associations, with that of the FS being statistically significant. The addition of one standard deviation in the area of FWS land holdings as a proportion of county land base (roughly 0.04) is associated with a factor change of 0.84 ($=0.014^{0.04}$) in the expected institution count (Figure 10). This result is not surprising because most FWS lands are part of the National Wildlife Refuges System, where resource extraction of woody biomass is very limited due to land use mandates. Conversely, the addition of one standard deviation in the area of FS land holdings as a proportion of county land base (roughly 0.17) is associated with a 1.21 ($=3.122^{0.17}$) factor increase in the expected institution count (Figure 11). None of the other major land holding agencies in the U.S. had a significant effect on the count of institutions using a woody biomass heating system. These results were largely expected for a couple of reasons. First, much of the land administered by the FS is forested and under active management to meet a wide range of management objectives and many activities generate biomass. Second, the FS and BLM work closely with the DOE in implementing federal policy instruments that encourage the use of woody biomass, and personnel in these agencies work to facilitate many biomass grants and expansion opportunities, as well as educational opportunities. Access to FS personnel and resources is improved close to where FS has offices and operations. Third, the Wood2Energy database focuses on the use of forest-derived woody biomass that is readily available on a majority of FS lands, but less prominent on BLM lands, as many of BLM's land holdings are dominated by woodlands (e.g. pinyon-juniper woodland) and rangeland, much of which is used for grazing or fossil-fuel and mineral resource extraction. For these reasons the presence of FS land holdings has a significant positive impact on the number of institutions using woody biomass that is derived from forest landscapes, as expected, while the same effects of BLM lands were expected to be less impactful and potentially more ambiguous in nature, as observed.

Other changes when comparing Model 2 to Model 1 include an increase in p-value for 'Heating Degree Days' in the inflated portion of the model, a decrease in p-value for 'Total Policies' in the NB portion, and an increase in p-value for 'Road Density' and 'Port Capacity' as these became less statistically significant in the NB portion of Model 2. After separating federal land ownership, heating degree days lost significance in the inflated portion of the model. In addition, 'Total Policies' in the NB portion of Model 2 remains insignificant ($p = 0.20$) with a negative coefficient (-0.030). This result is counterintuitive given the prior work of Aguilar et al. (2011) and Song et al. (2012a) who note that biomass consumption in the commercial sector, of which includes institutions, is not driven by higher priced alternative fuels or increased energy costs alone, but is also affected by regional government incentives through a variety of policy instruments.

Model 3 – Model Extension

To understand this phenomenon further, Model 3 separates 'Total Polices' into the following policy types: 'Tax Incentives', 'Cost Share and Grant' programs, 'Rules and Regulations', 'Financing' policies, 'Procurement' policies, and 'Technical Assistance' programs (Table 5, Model 3) based on prior work by Becker et al, (2011b). A description of policy types targeting biomass use can be found in Table 1. Among the policy types examined, 'Financing' policies encourage institutional use of woody biomass the most, and 'Procurement' policies appear to have a negative effect. It is worth emphasizing here the 'Procurement' policies are not focused on biomass procurement or technology acquisition, but rather net metering on utility grids procurement or bio-based products and fuels. While financial policies have a statistically insignificant p-value of 0.14, there is still some evidence that the addition of a financial policy in an average county increased the expected number of institutions by a factor of 1.20 (Figure 12). This gives suggestive but inconclusive evidence in support of the theory that large financial startup costs are a major barrier to new decentralized biomass facilities, and that financing policy may help.

On the other hand, the addition of a procurement policy changes the expected number of institutions using woody biomass by a factor of 0.73, which holds economic and statistical significance (Figure 13). This negative effect may be driven by the indirect and inadequate nature of procurement instruments in spurring woody biomass use in areas with high ecologic or economic barriers. Also there may be unobserved heterogeneity in the 'Procurement' policy variable that is not explained within the model. On the other hand, procurement policies may not be firmly directed at decentralized woody biomass use. For example, net metering may require local utilities to buy back excess electricity produced by biomass facilities, but most decentralized woody biomass facilities do not produce electricity and instead produce heat for space heating needs only.

Other policy instruments included in the study are largely insignificant with IRRs that are very close to one, meaning an additional policy will have very little influence on the number of institutions using decentralized biomass heating systems. This may be the result of many biomass policies in general not efficiently or effectively targeting small decentralized biomass heating systems, but rather are focusing primarily on the manufacturing and utility sectors, as supported by Becker et al. (2011b). In addition the small degree of cross sectional variation in policy types, which are measured at the state level rather than including county policies as well, may be limiting the statistical associations that can be drawn (Hitaj, 2013).

Another result derived from examining the three models progressively is that the increase in the median 'House Value' p-value from less than 0.01 in Model 1, to 0.01 in Model 2, and 0.07 in Model 3. In Model 1 the increase of a median household value by the standard deviation of \$80,000 resulted in just under a 1.38 ($=1.004^{80}$) factor increase in the expected number of institutions using biomass, whereas Model 3 only shows a 1.17 ($=1.002^{80}$) factor increase. The reduction in p-value and economic significance may indicate that the effect of affluence level on the number of institutions using biomass weakens when taking federal land owners and policy types into account. Also a drop in p-value may be the result of lost degrees of freedom as more variables are added to the model.

With the exception of 'Heating Degree Days', 'House Value', and 'Port Capacity', both model extensions described above did not significantly affect any other variables within the NB models. The affected variables all experienced increasing p-values which may be a result of lost degrees of freedom or may indicate that as federal land owners and policy types are taken into account the affected variables have less effect on the count of institutions using a woody biomass heating system.

Model Comparison and Expansion Map

Likelihood ratio tests were carried out for model comparison between Model 2 and the nested Model 1 and between Model 3 and the nested Model 2 (Table 8). Comparing Model 2 with Model 1, I obtained a chi-squared value of 12.50 with a corresponding p-value of 0.052 giving mild evidence that Model 2 is preferred. A comparison of Model 3 with Model 2 resulted in a chi-squared value of 11.65 with a corresponding p-value of 0.040 giving moderate evidence that Model 3 is preferred over Model 2. With this information it was determined that Model 3 is the preferred model and is used to make in-sample predictions for expected industry expansion. The resulting expansion map along with coefficients and interpretations above can serve as a guide to locate counties and specific areas that would be good focal points for adoption efforts and associated assistance programs.

Figure 14 displays a map of counties that are good targets for industry expansion of woody biomass heating systems as predicted by Model 3. Cutoff thresholds were defined in a two stage process—counties with residuals less than -0.5 are defined as likely adopters and counties with residuals less than -1.0 are defined as most likely adopters. Future likely adopters include counties in the Northwest, Northeast, Michigan, Colorado, and Otero County, New Mexico, while most likely adopters include counties in the Northwest and Northeast. For a complete list of likely and most likely adopter refer to Appendix C. Aside from being defined by residual values linked to Model 3, in general, these counties have one or more favorable conditions in common including higher than average heating needs, access to forest residues or biomass from planned NFP operations, high energy prices as proxied by commercial natural gas prices, high affluence levels proxied by median house value, and high portions of FS land ownership.

Discussion

Within the context of classic economic theory, all three principal location restrictions (physical, economic and technical) hold some influence on an institution's decision-making process when considering the installation of a decentralized biomass heating system. Influential physical restrictions include forest residues and available biomass as a result of the implementation of the NFP, while influential economic restrictions include cost structures that are associated with commercial natural gas prices and median house value. The satisfaction of these physical and economic restrictions, which dictate the location of successful biomass facilities, is a prerequisite for the successful deployment of decentralized biomass heating technologies. Furthermore, the selection and installation of decentralized biomass heating systems, is characterized by infrequent timing of installation, high upfront fixed capital costs with a long payback period, and technological advances that produce new technologies with a limited history of deployment. This environment puts physical and economic restrictions at the forefront of the decision-making process. For this reason increased scrutiny must be placed on the location of adopting institutions to make sure these satisfy the physical and economic restrictions for an optimal biomass heating system location before technology and administrative processes are put in place to overcome any technical restrictions. The aforementioned stems from the limiting factor of technical restrictions, where technical perfection demands location perfection, of which the latter is dependent on physical and economic restrictions.

On the other hand when considering the variable types as defined by Regional Science, location factors have the most influence in all three models, followed by external factors and internal factors. Influential location factors, which are highly dependent on absolute and relative geographic characteristics of a county, include forest residues as a result of active forest management, available biomass as a result of land treatments under the NFP, median house value, and the proportion of lands held by federal agencies. Influential external factors, which are those that are not in direct control of the institutions or the process to establish new institutions but which are affected, include commercial natural gas prices, and to a lesser degree heating degree days and select policies, most notably procurement policies. An influential internal factor is population density, which serves as a proxy for intra-county mechanisms to determine if institutions are needed. Inter-institutional factors were not included in this study because of the limitations of the Wood2Energy database. In addition, a detailed conversation of the spatial structure in the context of this research can be found in Appendix D.

Holistically, our models indicate that institutional adoption of woody biomass heating is driven by the availability of woody biomass resources, heating needs, and fossil-fuel prices as both logic and theory suggest. As expected, access to woody biomass through active forest management is associated with increased predicted probability of an institution using a woody biomass heating system. Biomass available due to reductions in forest fuel loads under the NFP is associated with an increase in the predicted number of institutions using woody biomass. In addition, higher priced commercial natural gas and higher median house values were hypothesized to be associated with an increase in the predicted number of institutions using biomass, while expectations about the association of total polices with the expected count of institutions did not hold as total policies showed a negative association with the expected number of woody biomass using institutions.

However these factors alone do not fully explain the variation in the adoption of woody biomass technologies by institutions. There is evidence that active land management practices of the FS may also be a significant driver of the adoption of woody biomass heating systems. In addition to the FS generating a supply of fuel, this effect may be the result of improved awareness and access to grant money associated with FS land management policy and programs, or it may be the effect of positive local attitudes toward wood heating practices that are usually associated with living close to working forest. Also, the negative sign on the road density coefficient may be capturing positive attitudes towards wood heating that is commonly seen in rural communities. Positive rural attitude towards biomass heating outweighs that of local infrastructure requirements needed to obtain woody biomass as a fuel source for decentralized heating systems, resulting in the negative sign of the road density coefficient. Though roads are required for biomass transportation, high road density may be indicative of suburban and urban areas that are less likely adopters of these systems.

The negative effect of total policies on institutions conflicts with prior results of Aguilar et al. (2011), who highlight policies as one of the potential driving forces for using woody biomass as a fuel source. With that said, after separating 'Total Policies' by policy type there is some suggestive evidence that the presence of financial policies may support the adoption of biomass heating systems by alleviating large start-up costs that take an extended period of time to recoup (Paepe, et al., 2006). On the other hand, there is evidence that procurement policies may actually have a negative effect on the progress of woody biomass heating systems or, alternatively, that procurement policies do not effectively target woody biomass, or have been implemented in areas where other factors form significant barriers to adoption. Some counties in the U.S. that are perfectly situated for woody biomass use may not be able to overcome other barriers like large start-up costs, or local attitudes against woody biomass use, which can be driven by fears of increased air pollution, most notably those related to particulate matter emissions. In general it appears that pro-biomass energy polices may not be effectively targeting small decentralized biomass heating systems, and are instead more focused on the manufacturing industry as supported by Becker et al. (2011b). It is worth noting that, though level of active management resulting in biomass production is not a policy variable per se, it has important policy dimensions. Both federal land management practices and resources allocated to fuel treatments under NFP are highly subject to public policy decisions, including budget allocations for forest restoration and fuels treatments.

One extension of this research would be to make an effort to expand the dataset to a panel dataset that would include the adoption year of institutions currently using biomass, and firm internal variables like the fuel source, the number of employees tasked with boiler operations, and the quantity of heating space. Panel data would allow for additional controls in stationarity, as well as stronger inferences of causality. Another extension would be to further examine policy incentives, especially financial policies, to see if these are strengthened by the presence of public service policies that inform the public about the benefits of biomass use (Aguilar and Saunders, 2010). A third possible extension would be to examine the association between woody biomass use in institutions and specific policy incentives that are delineated by which segment of the biomass supply chain they are intended to impact, as defined by Becker et al. (2011b). Yet another area of interest would be to further examine financial incentives to determine what the long term effects are of financial incentives in promoting decentralized biomass heating systems. A final extension of this research would be using this analysis as a base case to explore other barrier and limiting factors that may have an effect on the adoption of institutional biomass use. One example is to test the hypothesis that fears of increased air pollution may have a negative effect on the adoption of decentralized biomass heating systems. This hypothesis could be explicitly tested by including variables designed to capture county level non-attainment areas as determined by the U.S. Environmental Protection Agency (EPA).

Conclusions

This research has expanded the limited knowledge of policy effects and economic factors associated with institutional adoption of decentralized biomass heating systems. The relationship between adoption and public policy, both at the state and federal levels, is among the strongest outcomes of this study. Because of the strong relationship between forest management and adoption, future policy designed to incentivize the use of biomass in decentralized heating should be focused on land management polices rather than state policies directed towards biomass promotion. In addition, if biomass promotion through state policies is the desired policy instrument, it may be advantageous for state polices to better integrate the goals of federal land policy, including those of the NFP. If the goal of policy is to increase biomass use through the adoption of heating systems that use biomass as fuel, one may consider drafting state and federal policies that improve the health of our nation's forests through active forest management. This would include increasing the quantities of biomass removals under the NFP, as well as drafting policy designed to educate the public of the benefits of active forest management that includes the removal and use of biomass as fuel.

In addition, this research can be used by key stakeholders to inform successful installation and operation of decentralized biomass heating systems, with an eye on key factors that characterize successful adoption. Key factors desired for successful adoption include active local forest management, high energy prices, high affluence levels, and high heating needs. Using the information provided in this publication, an individual institution can make informed decisions on the installation of decentralized biomass heating systems when the time comes to upgrade their current heating technology. In addition, access to local federal personnel with knowledge of federal projects and programs, as well as financial assistance through state financing policies, may help reduce risks associated with large investment costs for institutions, which would allow for additional flexibility when developing supply chain logistics and biomass supply over the life of the project..

Stakeholders at the institutional level could gain additional knowledge from the inclusion of inter-institutional factors of adopting institutions such as the fuel source of both the old fossil fuel system and the new woody biomass heating system, the number of employees tasked with boiler operations, and the quantity of heating space. Knowing the effects of these variables will further inform institutions of the pros and cons of adopting a woody biomass heating system. For example, knowing which fossil fuels are most susceptible to substitution by woody biomass would help both institutions and governments refine their selection process for ideal adoption sites where efforts encouraging woody biomass heating systems are likely to be most effective and efficient.

Furthermore, this research provides an expansion map of counties with institutions not currently using decentralized biomass heating systems that have favorable conditions for adoption. As market conditions for institutional heating improve, it will also affect the adoption rate of biomass heating systems. For example, if under the NFP there were an increase in treatment where biomass removal is planned, these areas would expect to see a higher predicted number of institutions using woody biomass heat. Likewise counties with increasing affluence may experience additional institutions using biomass heating systems, while areas with population growth or increasing urbanization may experience fewer predicted institutions using biomass heat. Also, an increase in state sponsored financing policies in support of decentralized biomass heating systems may increase the rate of adopting counties. In addition, expansion maps can be used in concert with land cover data to determine what vegetation types are the most conducive to increased institutional biomass use in decentralized heating systems, with implicit ties to vegetation types that commonly produce timber or receive fuel treatments, or both.

While centralized distribution systems are well established to provide fossil-fuels for traditional heating systems, the current state of decentralized woody biomass heating systems is in its infancy in the U.S. As global atmospheric greenhouse gas concentrations and renewable energy use continue to rise, institutions may look beyond traditional fossil-fuels to fill their heating needs. This analysis serves, in part, as a path forward because it highlights factors that are important when deciding what regions and counties of the U.S. should be targeted for the successful expansion of decentralized woody biomass heating systems. The successful expansion of small decentralized woody biomass heating systems may help induce biomass demand and active forest management as local woody biomass markets reach a mature scale. Mature decentralized biomass markets can reduce the economic uncertainty that currently characterizes nascent markets, further catalyzing other localized bio-market expansions. This may further facilitate forest restoration and fuel reduction activities by providing new markets for wood biomass byproducts of forest management.

Table 1. Policy instruments that encourage the use of forest based woody biomass.

Policy Type	Policy Examples/Description
Tax Incentives	Sales tax credits—Reduction or exemption in state sales tax for qualified purchases of equipment designed to harvest, transport, or process biomass. Corporate or Production tax credits—Reduction or exemption in taxes based on use of biomass or production of biomass energy products. Personal tax credits—Reduction in income tax or tax credits for individual who have installed qualified renewable energy systems. Property tax credits—Reduction in property tax or tax credits for property (including equipment) used to transport biomass or site biomass facilities.
Cost Share and Grants	Cost-Share—Funds biomass use through fee waivers or additional resources used to purchase or operate biomass related equipment. Grants—Funds biomass use through competitive grants that can be used to purchase biomass equipment as well as biomass research and development. Rebates—Funds biomass use by paying for the purchase and/or installation of qualified biomass technologies.
Rules and Regulations	Renewable Energy Standards—The requirement that a percent of utility companies energy sales be derived from renewable sources. Interconnection Standards—Grid connection governance Green Power Programs—Option to consumers to purchase energy derived from renewable resources. Public Benefit Funds—Portion of monthly energy bill is used for renewable energy development. Equipment Certifications—Minimal efficiency standards for biomass processing equipment Harvest Guidelines—A set of best management practices for removing and procuring biomass
Financing	Bonds—Government borrowing to finance construction of biomass boilers that heat industrial and institutional facilities. Loans(Micro, low interest and zero interest)—Financial support for the purchase of equipment
Procurement	Procurement—Mandates or incentives to use bio-based products when constructing, processing, heating, or operating equipment or motor vehicles. Net Metering—Local utilities are required to buy back excessive electric generation from renewable sources
Technical Assistance	Training Programs—Develops technical expertise of business owners and staff through courses and certification. Technical Assistance—Helps coordinate research and disperse information, as well as offer assistance in grant writing and business planning.

Note: This table was derived from Table 1 in Becker et al., 2011b.

Table 2. Independent variables used to estimate the ZINB model parameters.

Variable	Type	Description/ (Resolution)	Units	Source
Y_i - Dependent Variable				
Institutions	N/A	Institutions currently using biomass heating systems	Count	Wood2Energy, 2014
β - Zero Inflated (ZI-Binary)				
Heating Degree Days	External	1981 to 2010—Total average heating degree days (county)	Continuous (Thousands)	National Oceanic and Atmospheric Administration, 2014
Population Density	Internal	2010—Population per 1000 meter^2 (county)	People per 1,000,000 m^2	U.S. Census Bureau, 2013
Forest Residue	Location	2007—logging residues and other removable (county)	10,000,000 m^3	USDA, USFS Timber Product Output, 2007
γ - Negative Binomial (NB-Count)				
Heating Degree Days	External	1981 to 2010—Total average heating degree days (county)	Continuous (Thousands)	National Oceanic and Atmospheric Administration, 2014
Natural Gas Prices	External	2008 to 2010—Commercial natural gas three year average price (state)	Dollars ($) per 1,000 ft^3	U.S. Energy Information Administration, 2013
House Value	Location	2008 to 2012—Median Value of owner-occupied housing (county)	Thousand Dollars ($)	U.S. Census Bureau, 2013
Forest Residue	Location	2007—Logging residues and other removals (county)	10,000,000 m^3	USDA, USFS Timber Product Output, 2007
Biomass Planned	Location	2006-2010—Biomass removal planned in National Fire Plan (NFP) (county)	1,000,000 m^2	National Fire Plan Operating and Reporting System, 2006-2010
Federal Land	Location	2005, 2012—Proportion of land managed by Federal Agencies[a] (county)	Proportion	ESRI, National Atlas of the U.S. and the U.S. Geological Survey, 2005 and 2012
Total Policies	External	2011—Total number of state policies that effect forest biomass use directly or indirectly. Federal policies are not included. (state)	Discrete (Absolute)	Becker, Moseley, and Lee, 2011b
Population	Internal	2010—Population (county)	100,000 people	U.S. Census Bureau, 2013
Road Density	Location	2013—Primary (interstates) and secondary road (main state and county highways) (county)	Meters of road per 1,000 m^2	U.S. Census Bureau, 2013
Port Capacity	Location	2008 to 2012, Average port capacity of principal ports. (county)	Short tons (100,000)	U.S. Army Corps, Navigation Data Center, Waterborne Commerce Statistics Center, 2014
County Area	Location	2010—County Area	Billion m^2	U.S. Census Bureau, 2013

[a] Land section 640 acres or larger are included. Private in-holdings less than 640 acres may be accounted for in federal holdings.

Table 3. Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
Institutions	3143	0.127585	0.675534	0	16
Heating Degree Days	3143	4.996686	2.191648	0.002182	19.09467
Population Density	3143	1.001250	6.657018	0	268.2155
Natural Gas Prices	3143	10.43197	1.830150	7.38	35.18666
House Value	3143	131.8983	80.61617	0	944.1
Forest Residues	3143	2.466242	4.632817	0	70.0118
Biomass NFP	3143	2.415140	12.80937	0	250.9294
Proportion Federal Lands*	3143	0.126889	0.239603	0	1.062016
Proportion NPS	3143	0.007012	0.044470	0	1
Proportion FWS	3143	0.006063	0.038947	0	0.991935
Proportion FS**	3143	0.070367	0.174619	0	1.017979
Proportion DOD	3143	0.009084	0.034431	0	0.742139
Proportion BOR	3143	0.000454	0.003458	0	0.106793
Proportion BLM	3143	0.020063	0.089649	0	0.952367
Proportion BIA	3143	0.011352	0.076405	0	0.998639
Total Policies	3142	7.247295	3.757148	2	15
Cost Share Grants	3142	0.931891	1.279653	0	6
Technical Assistance	3142	1.488542	1.570085	0	6
Financing	3142	0.543921	0.675076	0	3
Procurement	3142	1.305856	1.026406	0	4
Rules and Regulations	3142	1.048695	1.222930	0	3
Tax Incentives	3142	1.928390	1.973793	0	10
Population	3143	0.982328	3.129012	0.00082	98.18605
Road Density	3143	0.204257	0.199780	0	2.650168
Port Capacity	3143	1.013043	9.286781	0	234.2816
County Area	3143	2.910467	9.353530	0.00518	376.8557
Latitude	3142	18.40748	63.69796	-126.638	433.3846
Longitude	3142	34.46994	104.9199	-621.637	219.9037
West Coast	3143	0.020045	0.140175	0	1
South	3143	0.258988	0.438149	0	1
Lake States	3143	0.104995	0.306596	0	1
Northeast	3143	0.077633	0.267636	0	1
Northwest	3143	0.072224	0.258900	0	1
Midwest	3143	0.255170	0.436026	0	1
Southwest	3143	0.050270	0.218537	0	1

* Proportion of federal land exceeds one because the numerator contains both federal land area and inland federal waterways, while the denominator contains only federal land area. This has resulted in a proportion of federal land above one for the following 22 counties from the smallest to highest proportion: Unicoi, Tennessee; Ketchikan Gateway, Alaska; Mineral, Colorado; Mineral, Nevada; Graham, North Carolina; Ziebach, South Dakota; Leslie, Kentucky; Sitka, Alaska; Union, Georgia; Summit, Colorado; Macon, North Carolina; Aleutians West, Alaska; Rabun, Georgia; Menominee, Wisconsin; Osage, Oklahoma; Corson, South Dakota; Sioux, North Dakota; Wade Hampton, Alaska; Teton, Wyoming; Mahnomen, Minnesota; Dewey, South Dakota.

** Proportion of FS land exceeds one for Wrangell, Alaska due to resolution differences in GIS data.

Table 4. Correlation matrix of variables selected for inclusion.

	Instit.	Heat D.D.	Pop. Dens.	N. G. Price	House Value	Forest Resid.	Biom. NFP	Prop. Fed.	Prop. NPS	Prop. FWS	Prop. FS	Prop. DOD	Prop. BOR	Prop. BLM	Prop. BIA	Total Pol.	C. S. Grant
Institutions	1.00																
Heating D.D.	0.19	1.00															
Pop. Density	-0.01	0.00	1.00														
Nat. G. Price	0.12	-0.38	0.05	1.00													
House Value	0.09	0.11	0.35	0.12	1.00												
Forest Resid.	0.17	-0.12	-0.05	0.23	-0.04	1.00											
Biomass NFP	0.06	0.05	-0.02	-0.05	0.09	0.10	1.00										
Prop. Fed.	0.06	0.19	-0.05	-0.12	0.19	0.05	0.35	1.00									
Prop. NPS	0.01	0.05	0.01	0.08	0.16	-0.01	0.06	0.29	1.00								
Prop. FWS	0.00	0.07	-0.01	-0.01	0.03	-0.01	0.01	0.18	0.06	1.00							
Prop. FS	0.08	0.11	-0.05	-0.06	0.16	0.11	0.27	0.79	0.06	-0.04	1.00						
Prop. DOD	-0.01	-0.12	0.00	0.06	0.05	0.00	0.05	0.16	0.00	0.04	-0.03	1.00					
Prop. BOR	-0.01	0.07	-0.01	-0.09	0.06	-0.05	0.05	0.17	0.04	0.01	0.06	-0.01	1.00				
Prop. BLM	0.00	0.15	-0.03	-0.15	0.10	-0.08	0.24	0.51	0.09	0.06	0.10	0.05	0.24	1.00			
Prop. BIA	0.00	0.14	-0.02	-0.09	-0.03	0.01	0.13	0.36	0.02	-0.01	0.01	0.01	0.03	0.05	1.00		
Total Policies	0.03	0.21	0.03	-0.08	0.21	-0.01	0.10	0.07	0.02	-0.04	0.07	-0.04	0.00	0.03	0.03	1.00	
C. S. / Grants	0.11	0.34	0.01	0.02	0.19	0.11	0.01	0.02	0.05	0.02	0.02	-0.05	-0.03	-0.02	0.04	0.60	1.00
Tech. Ass.	-0.02	-0.01	0.00	0.12	-0.01	0.01	0.01	-0.05	-0.01	-0.04	0.01	-0.02	-0.04	-0.08	-0.03	0.60	0.28
Financing	0.05	0.22	0.02	-0.14	0.16	-0.06	0.03	0.06	0.02	0.02	0.08	-0.03	-0.01	0.03	-0.02	0.24	0.10
Procurement	-0.02	0.05	0.12	-0.06	0.13	-0.10	-0.05	-0.09	-0.04	-0.05	-0.08	-0.01	-0.04	-0.04	0.00	0.16	0.13
Rules & Reg.	0.01	0.10	0.04	-0.16	0.12	-0.02	0.05	-0.06	-0.03	-0.04	-0.04	-0.07	0.00	0.00	-0.02	0.68	0.25
Tax Incent.	-0.01	0.03	-0.04	-0.08	0.09	-0.02	0.16	0.21	0.05	-0.01	0.16	0.03	0.07	0.14	0.09	0.45	0.01
Population	0.00	-0.08	0.33	0.06	0.36	-0.04	0.02	-0.01	0.05	0.00	-0.04	0.06	0.01	0.01	-0.01	0.12	0.11
Road Density	-0.01	-0.13	0.44	0.25	0.30	-0.07	-0.11	-0.23	-0.07	-0.06	-0.16	0.03	-0.08	-0.17	-0.10	-0.11	-0.04
Port Capacity	-0.01	-0.07	0.39	0.03	0.14	0.00	-0.01	-0.02	0.02	0.02	-0.02	0.00	-0.01	-0.02	-0.01	0.00	-0.01
County Area	0.10	0.24	-0.03	-0.09	0.04	0.00	0.15	0.28	0.19	0.31	0.06	0.03	0.07	0.33	0.07	-0.01	0.01
Latitude	0.20	0.90	0.02	-0.22	0.24	-0.04	0.06	0.25	0.15	0.20	0.14	-0.07	0.05	0.14	0.12	0.21	0.33
Longitude	0.08	-0.21	0.10	0.33	-0.09	0.09	-0.24	-0.44	-0.19	-0.16	-0.24	-0.01	-0.18	-0.39	-0.14	-0.18	0.06
West Coast	-0.02	-0.10	0.03	0.07	0.36	0.01	0.16	0.15	0.16	0.01	0.13	0.04	0.07	0.06	-0.01	0.21	0.12
South	-0.09	-0.70	-0.04	0.18	-0.22	0.18	-0.05	-0.14	-0.04	0.00	-0.09	0.04	-0.05	-0.13	-0.09	-0.25	-0.21
Lake States	0.00	0.38	-0.01	-0.14	0.00	0.02	-0.04	-0.07	-0.02	-0.03	-0.04	-0.06	-0.05	-0.08	0.02	0.26	0.52
Northeast	0.32	0.19	0.18	0.28	0.29	0.03	-0.05	-0.12	-0.03	-0.03	-0.09	-0.04	-0.04	-0.07	-0.04	0.07	0.13
Northwest	0.06	0.32	-0.03	-0.08	0.16	0.09	0.17	0.39	0.15	0.15	0.26	-0.02	0.13	0.29	0.11	0.14	0.02
Midwest	-0.08	0.24	-0.06	-0.30	-0.25	-0.23	-0.09	-0.18	-0.08	-0.05	-0.15	-0.02	-0.01	-0.13	0.03	-0.06	-0.10
Southwest	0.00	0.09	-0.02	-0.22	0.14	-0.12	0.20	0.39	0.02	0.01	0.20	0.05	0.13	0.50	0.11	0.06	-0.06

Table 4 continued. Correlation matrix of variables selected for inclusion.

	Tech. Ass.	Finan.	Proc.	Rules & Reg.	Tax Incen.	Pop.	Road Dens.	Port Cap.	Coun. Area	Lat.	Long.	West Coast	South	Lake States	North-east	North-west	Mid-west	South-west
Institutions																		
Heating D.D.																		
Pop. Density																		
Nat. G. Price																		
House Value																		
Forest Resid.																		
Biomass NFP																		
Prop. Fed.																		
Prop. NPS																		
Prop. FWS																		
Prop. FS																		
Prop. DOD																		
Prop. BOR																		
Prop. BLM																		
Prop. BIA																		
Total Policies																		
C. S. / Grants																		
Tech. Ass.	1.00																	
Financing	0.12	1.00																
Procurement	-0.13	-0.05	1.00															
Rules & Reg.	0.35	0.06	0.22	1.00														
Tax Incent.	-0.03	-0.05	-0.31	0.10	1.00													
Population	0.04	0.03	0.04	0.09	0.04	1.00												
Road Density	-0.02	-0.10	0.27	-0.07	-0.23	0.26	1.00											
Port Capacity	-0.01	-0.03	0.03	0.05	-0.02	0.40	0.19	1.00										
County Area	-0.06	0.02	-0.09	-0.01	0.07	0.03	-0.15	0.00	1.00									
Latitude	-0.05	0.22	0.01	0.05	0.12	-0.03	-0.09	-0.05	0.31	1.00								
Longitude	0.08	-0.18	0.25	-0.17	-0.40	0.00	0.45	0.01	-0.32	-0.31	1.00							
West Coast	0.12	0.10	-0.16	0.11	0.20	0.24	-0.05	0.04	0.06	0.03	-0.38	1.00						
South	-0.15	-0.34	-0.19	0.03	-0.01	-0.01	-0.04	0.05	-0.06	-0.68	0.10	-0.08	1.00					
Lake States	0.16	-0.14	0.06	0.34	-0.16	0.00	0.01	-0.01	-0.04	0.28	0.10	-0.05	-0.20	1.00				
Northeast	-0.07	0.05	0.23	0.17	-0.15	0.14	0.26	0.06	-0.03	0.22	0.38	-0.04	-0.17	-0.10	1.00			
Northwest	-0.17	0.12	-0.21	-0.01	0.47	-0.03	-0.21	-0.01	0.27	0.51	-0.53	-0.04	-0.17	-0.10	-0.08	1.00		
Midwest	0.05	0.34	0.00	-0.15	-0.11	-0.09	-0.18	-0.05	-0.06	0.13	-0.12	-0.08	-0.35	-0.20	-0.17	-0.16	1.00	
Southwest	-0.01	0.09	0.02	0.01	0.10	0.02	-0.14	-0.03	0.14	-0.03	-0.32	-0.03	-0.14	-0.08	-0.07	-0.06	-0.13	1.00

Table 5. Results for the Zero Inflated Negative Binomial (ZINB) Model 1, Model 2, and Model 3.

Dependent Variable: Institutions		Model 1				Model 2				Model 3			
	Independent Variables	Coef.	[OR] (IRR)	Robust SE	p-value	Coef.	[OR] (IRR)	Robust SE	p-value	Coef.	[OR] (IRR)	Robust SE	p-value
Zero Inflated (ZI-Logistic)													
	Heating Degree Days	-0.207**	[0.813]	0.105	0.05	-0.271	[0.763]	0.228	0.24	-0.255	[0.775]	0.190	0.18
	Population Density	-0.044*	[0.957]	0.025	0.08	-0.044	[0.957]	0.027	0.10	-0.043*	[0.957]	0.026	0.10
	Forest Residues	-2.021***	[0.133]	0.597	0.00	-2.086**	[0.124]	0.911	0.02	-2.009***	[0.134]	0.751	0.01
	_cons	2.862***		0.783	0.00	3.129**		1.542	0.04	3.012**		1.312	0.02
Negative Binomial (NB-Count)													
	Heating Degree Days	0.190*	(1.210)	0.099	0.05	0.178	(1.194)	0.109	0.10	0.138	(1.148)	0.104	0.18
	Natural Gas Prices	0.265***	(1.304)	0.056	0.00	0.298***	(1.347)	0.063	0.00	0.256***	(1.291)	0.063	0.00
	House Value	0.004***	(1.004)	0.001	0.00	0.003**	(1.003)	0.001	0.01	0.002*	(1.002)	0.001	0.07
	Forest Residues	0.003	(1.003)	0.007	0.62	0.001	(1.001)	0.007	0.84	0.002	(1.002)	0.007	0.77
	Biomass NFP	0.009**	(1.009)	0.004	0.01	0.012**	(1.012)	0.005	0.02	0.012**	(1.012)	0.005	0.01
	Prop. Federal Land	0.822***	(2.275)	0.300	0.01								
	Proportion NPS					-2.357	(0.095)	1.613	0.14	-2.180	(0.113)	1.572	0.17
	Proportion FWS					-4.241*	(0.014)	2.434	0.08	-4.606*	(0.010)	2.671	0.08
	Proportion FS					1.139***	(3.122)	0.304	0.00	1.082***	(2.951)	0.303	0.00
	Proportion DOD					1.661	(5.267)	2.920	0.57	1.690	(5.420)	2.846	0.55
	Proportion BOR					-11.895	(0.000)	30.453	0.70	-8.094	(0.000)	28.619	0.78
	Proportion BLM					-0.860	(0.423)	1.127	0.45	-0.719	(0.487)	1.194	0.55
	Proportion BIA					-0.698	(0.498)	1.119	0.53	-0.361	(0.697)	0.936	0.70
	Total Policies	-0.028	(0.972)	0.023	0.22	-0.030	(0.970)	0.024	0.20				
	Cost Share Grants									-0.103	(0.902)	0.095	0.28
	Technical Assistance									-0.007	(0.993)	0.067	0.92
	Financing									0.181	(1.199)	0.120	0.13
	Procurement									-0.313**	(0.731)	0.124	0.01
	Rules and Regulations									0.047	(1.048)	0.084	0.58
	Tax Incentives									-0.044	(0.957)	0.039	0.26
	Population	-0.001	(0.999)	0.030	0.98	0.004	(1.004)	0.030	0.89	0.017	(1.017)	0.029	0.57
	Road Density	-1.079*	(0.340)	0.629	0.09	-1.036	(0.355)	0.638	0.10	-1.081	(0.339)	0.659	0.10
	Port Capacity	-0.016**	(0.984)	0.008	0.05	-0.012	(0.988)	0.008	0.13	-0.012	(0.988)	0.008	0.11
	County Area	-0.001	(0.999)	0.002	0.49	0.004	(1.004)	0.003	0.14	0.004	(1.004)	0.003	0.11
	Latitude	0.010***	(1.010)	0.003	0.00	0.011***	(1.011)	0.003	0.00	0.012***	(1.012)	0.003	0.00
	Longitude	0.010***	(1.010)	0.002	0.00	0.008***	(1.008)	0.002	0.00	0.009***	(1.009)	0.002	0.00
	West Coast	2.009*	(7.457)	1.217	0.10	1.460	(4.305)	1.210	0.23	0.880	(2.410)	1.238	0.48
	South	1.132**	(3.101)	0.449	0.01	1.064**	(2.897)	0.474	0.02	0.605	(1.832)	0.446	0.17
	Lake States	1.517***	(4.560)	0.414	0.00	1.438***	(4.211)	0.428	0.00	1.386***	(4.000)	0.439	0.00
	Northeast	1.464***	(4.325)	0.372	0.00	1.456***	(4.288)	0.393	0.00	1.495***	(4.458)	0.488	0.00
	Northwest	3.019***	(20.466)	0.667	0.00	2.562***	(12.959)	0.697	0.00	2.259***	(9.577)	0.726	0.00
	Midwest	2.193***	(8.960)	0.458	0.00	2.011***	(7.474)	0.467	0.00	1.615***	(5.030)	0.425	0.00
	Southwest	4.246***	(69.825)	0.689	0.00	4.167***	(64.500)	0.688	0.00	3.778***	(43.708)	0.663	0.00
	_cons	-8.644***		0.971	0.00	-8.694***		0.987	0.00	-7.530***		0.990	0.00
lnalpha	_cons	-0.446		0.310	0.15	-0.425		0.377	0.26	-0.601		0.371	0.10
alpha		0.640***		0.199	0.00	0.654***		0.246	0.01	0.548***		0.203	0.01
N		3142				3142				3142			
Log Likelihood		-793.93				-787.68				-781.86			
Chi Square		447.27			<0.0001	454.46			<0.0001	560.35			<0.0001
% correctly predicted ± 0.499 residual		91.41%				91.53%				91.82%			

The base case for the regional control is South Appalachia. * *p*<0.1; ** *p*<0.05; *** *p*<0.01

Table 6. Tests of ZINB model fit.

	Vuong test[a] ZINB vs. NB		Likelihood ratio test[b] ZINB vs. ZIP	
	Statistic (V[c])	p-value	Statistic (z-score)	p-value
Model 1	4.45	<0.0001	46.37	<0.0001
Model 2	3.89	0.0001	74.12	<0.0001
Model 3	3.90	<0.0001	65.53	<0.0001

[a] H_0: NB is preferred to ZINB.
[b] H_0: ZIP is preferred to ZINB.
[c] V is the Vuong statistic as described in Vuong, 1989.

Table 7. Actual count versus predicted count.

Institutions	Actual	Predicted	Difference
Model 1			
0	92.84%	92.61%	0.23% pts.
1	04.87%	05.83%	-0.96% pts.
2	01.15%	01.25%	-0.10% pts.
3	00.60%	00.25%	0.35% pts.
4	00.16%	00.05%	0.11% pts.
5	00.06%	00.01%	0.05% pts.
Model 2			
0	92.84%	91.93%	0.91% pts.
1	04.87%	06.46%	-1.59% pts.
2	01.15%	01.31%	-0.16% pts.
3	00.60%	00.25%	0.35% pts.
4	00.16%	00.04%	0.12% pts.
5	00.06%	00.01%	0.05% pts.
Model 3			
0	92.84%	90.71%	2.13% pts.
1	04.87%	07.24%	-2.37% pts.
2	01.15%	01.64%	-0.49% pts.
3	00.60%	00.33%	0.27% pts.
4	00.16%	00.06%	0.10% pts.
5	00.06%	00.01%	0.05% pts.

Note: Actual, Predicted, and Difference values for institution counts 6 to 16 are not included, but are all <00.01% and <00.01% pts, respectfully.

Table 8. Likelihood ratio test for model comparison of fit.

	d.f.	Chi Square	p-value
Model 1 nested in Model 2	6	12.50*	0.0516
Model 2 nested in Model 3	5	11.65**	0.0399

* *p*<0.1; ** *p*<0.05; *** *p*<0.01

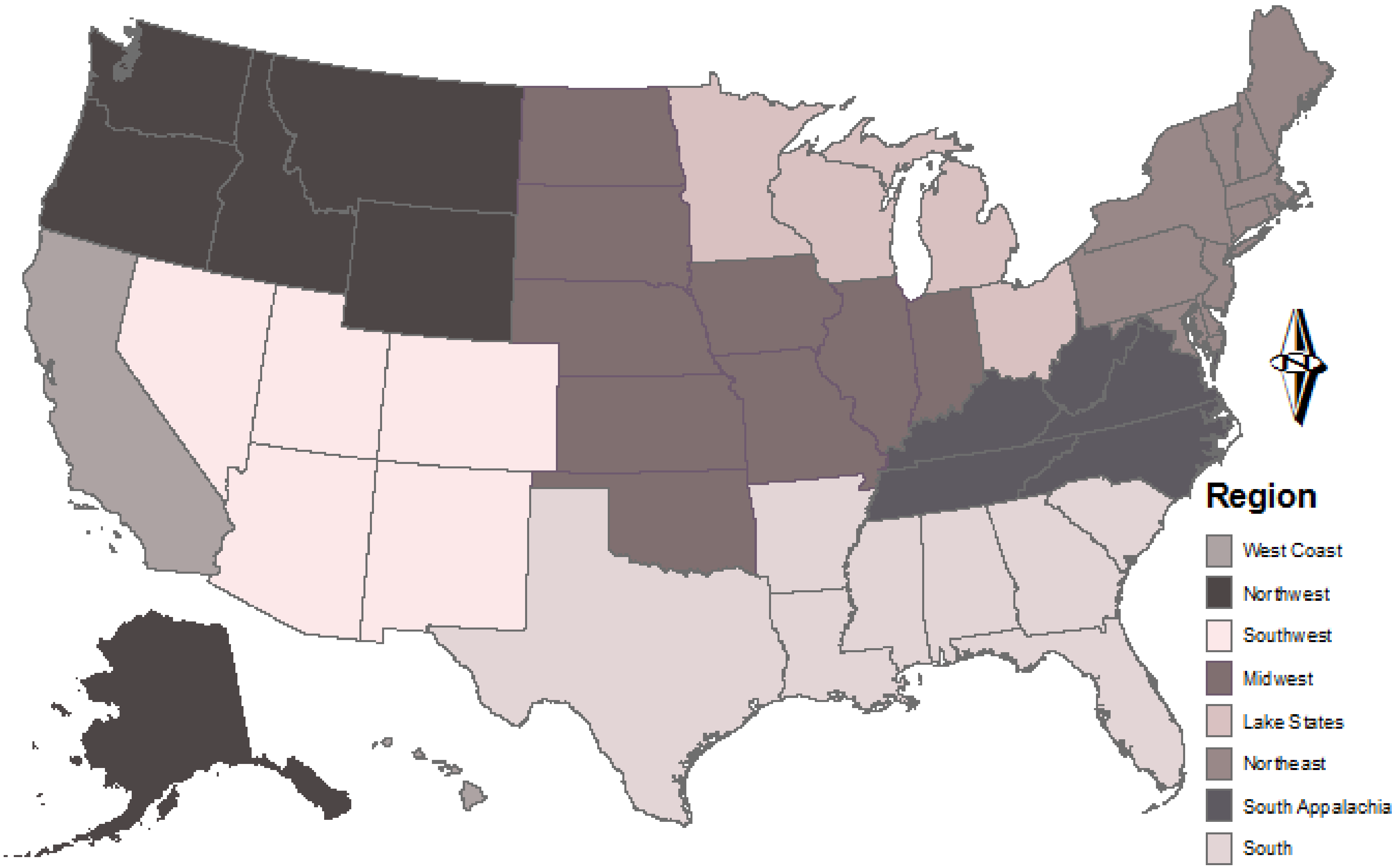

Figure 1. Map of regions used as indicator variables

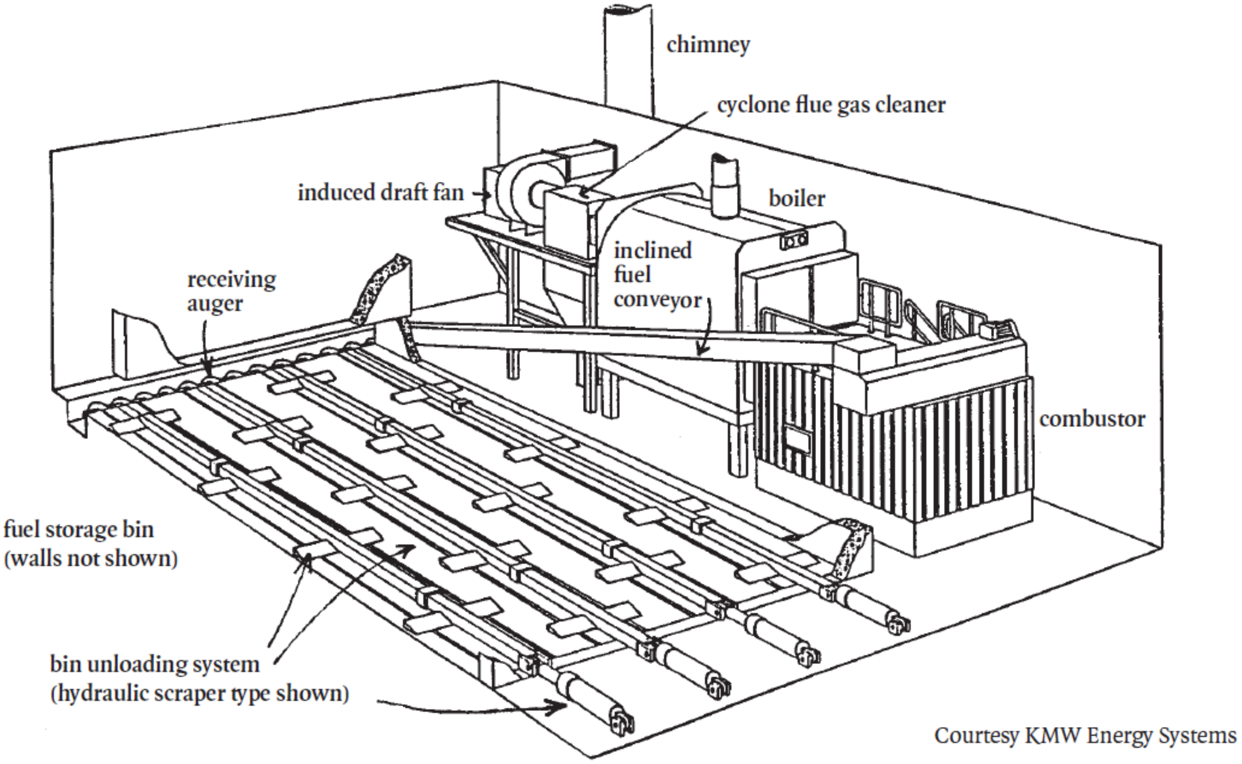

Figure 2. Basic Biomass Heating System (Maker, 2004).

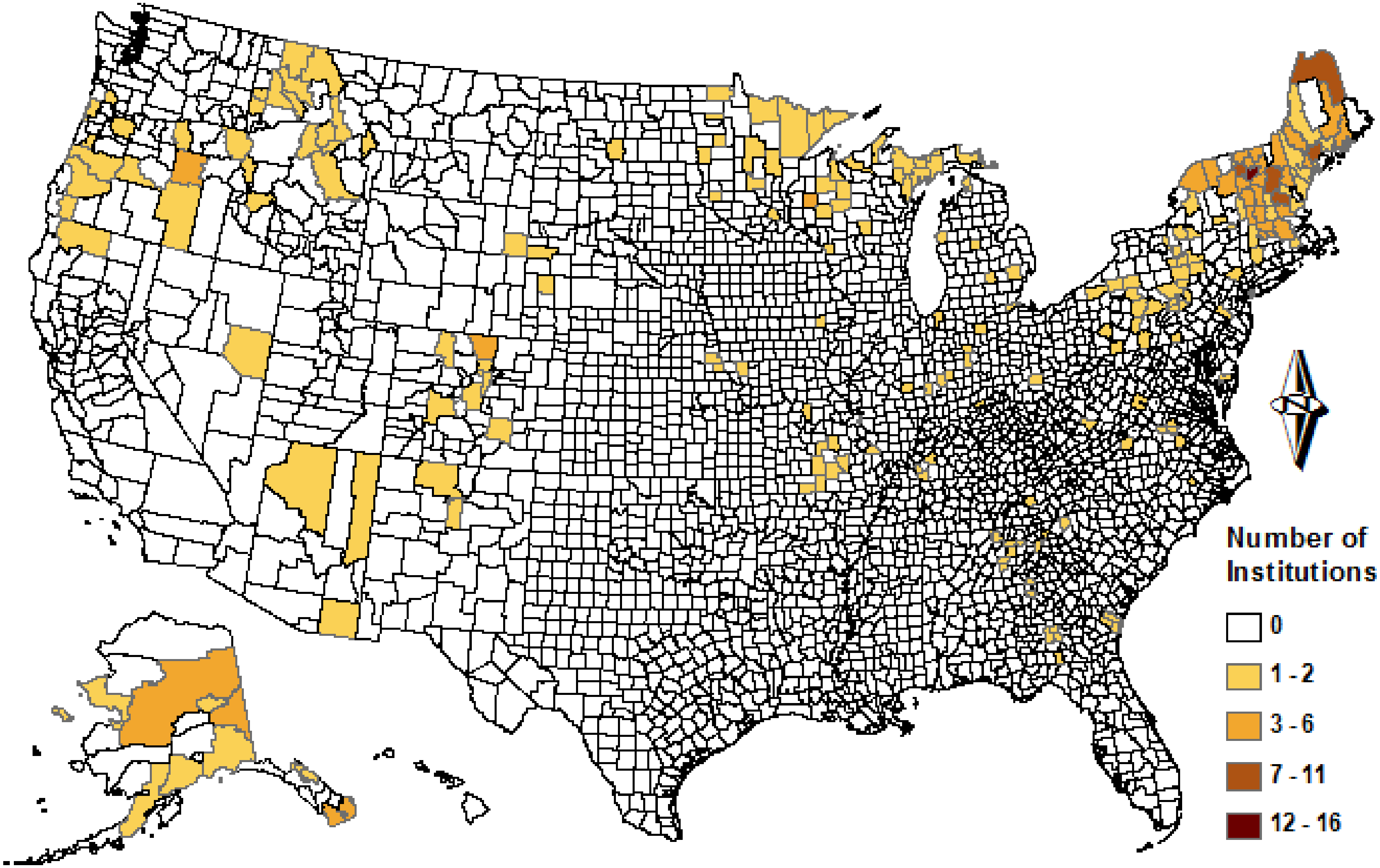

Figure 3. County map of institutions currently using woody biomass as a primary heating fuel (W2E, 2014).

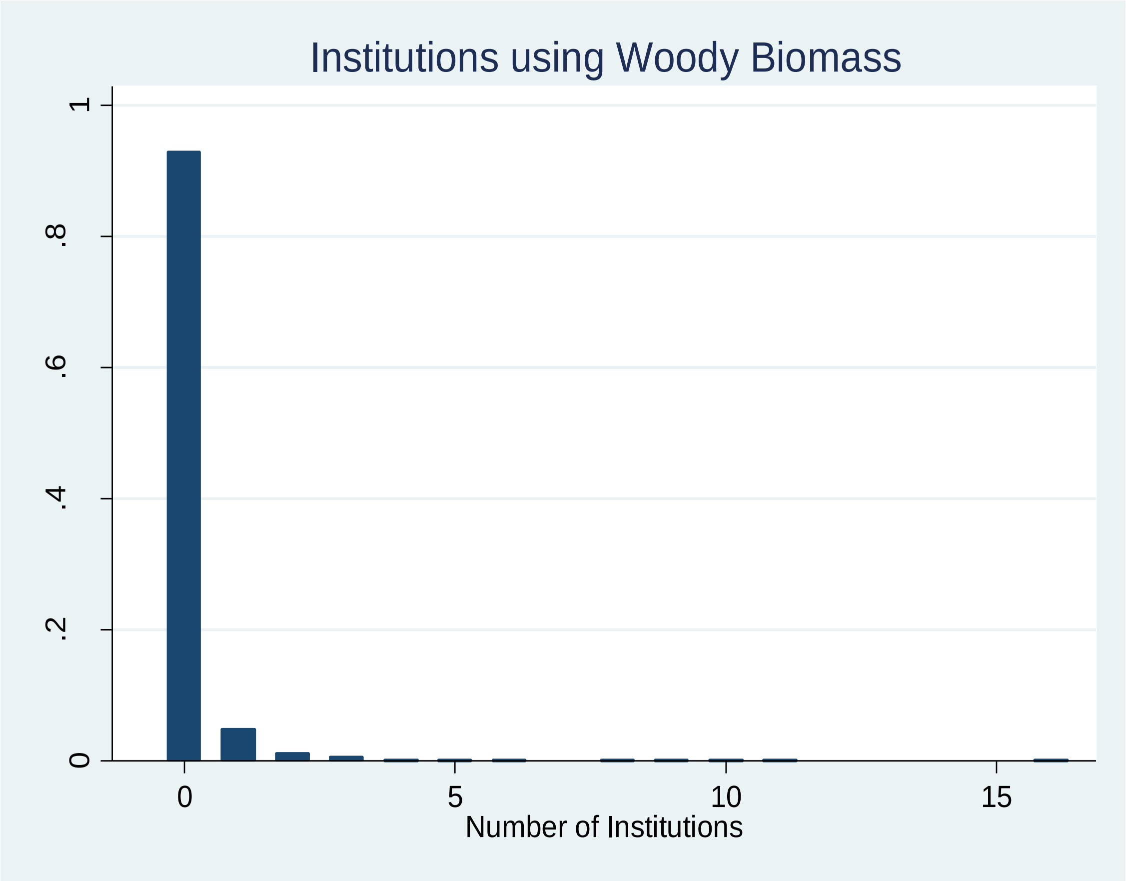

Figure 4. Histogram of institutions using woody biomass by county.

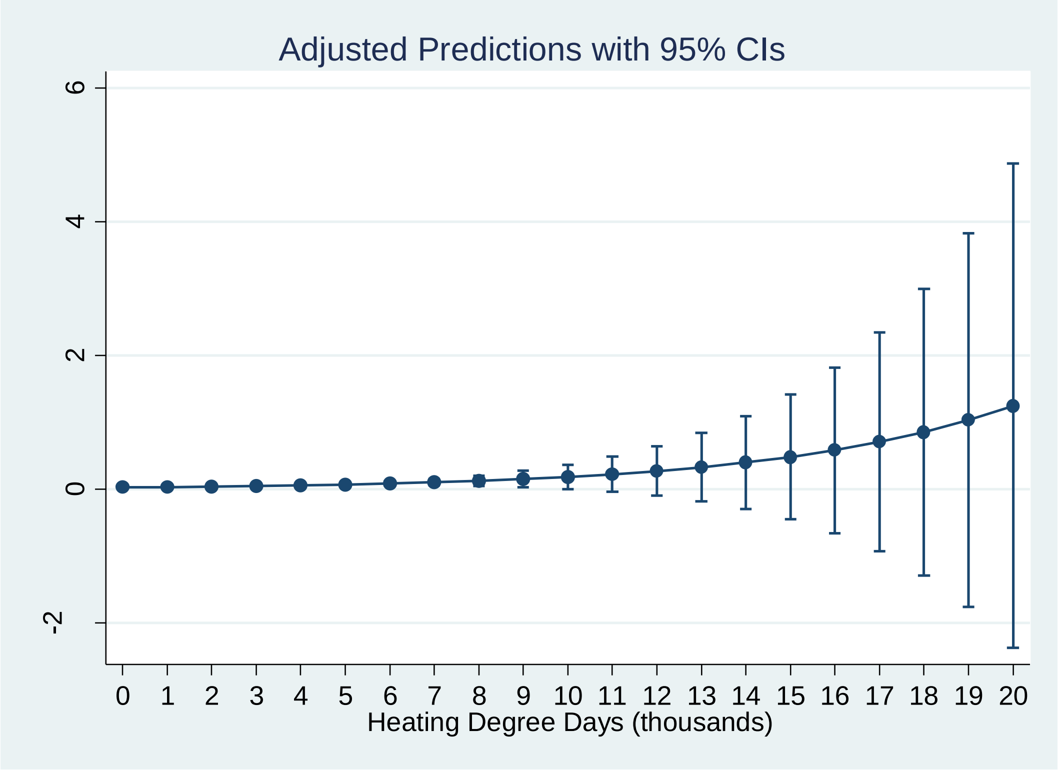

Figure 5. Expected number of events as heating degree days increases, holding all other variables constant at their means (Model 1, NB).

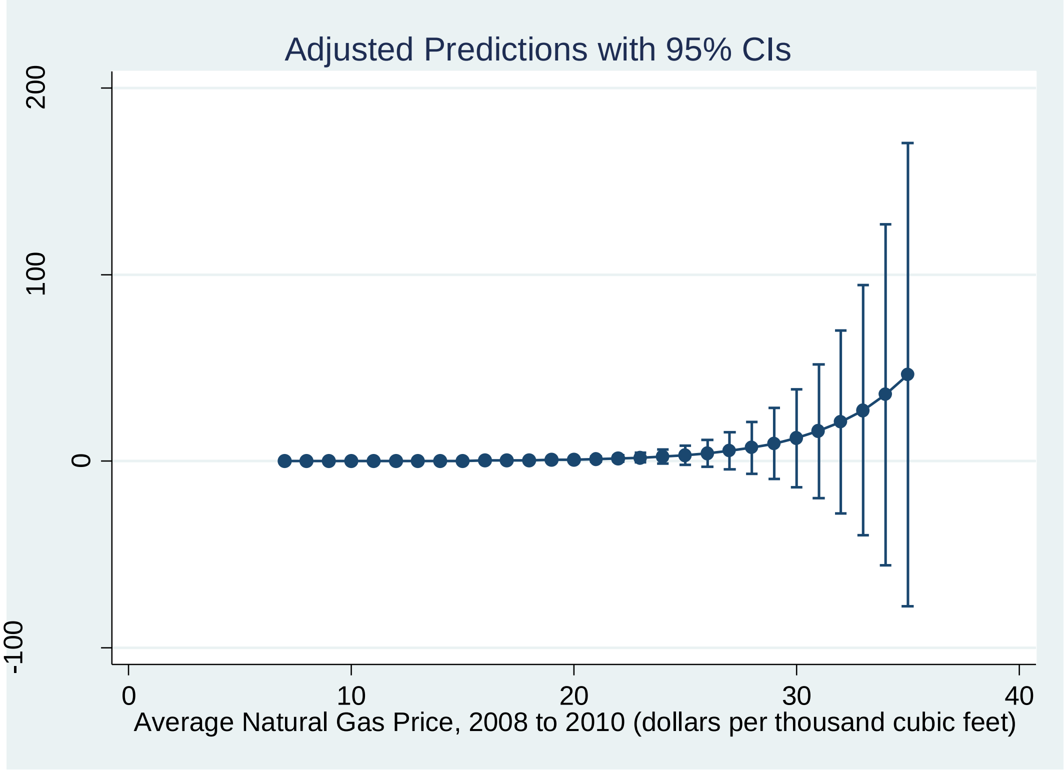

Figure 6. Expected number of events as natural gas price increase, holding all other variables constant at their means (Model 1, NB).

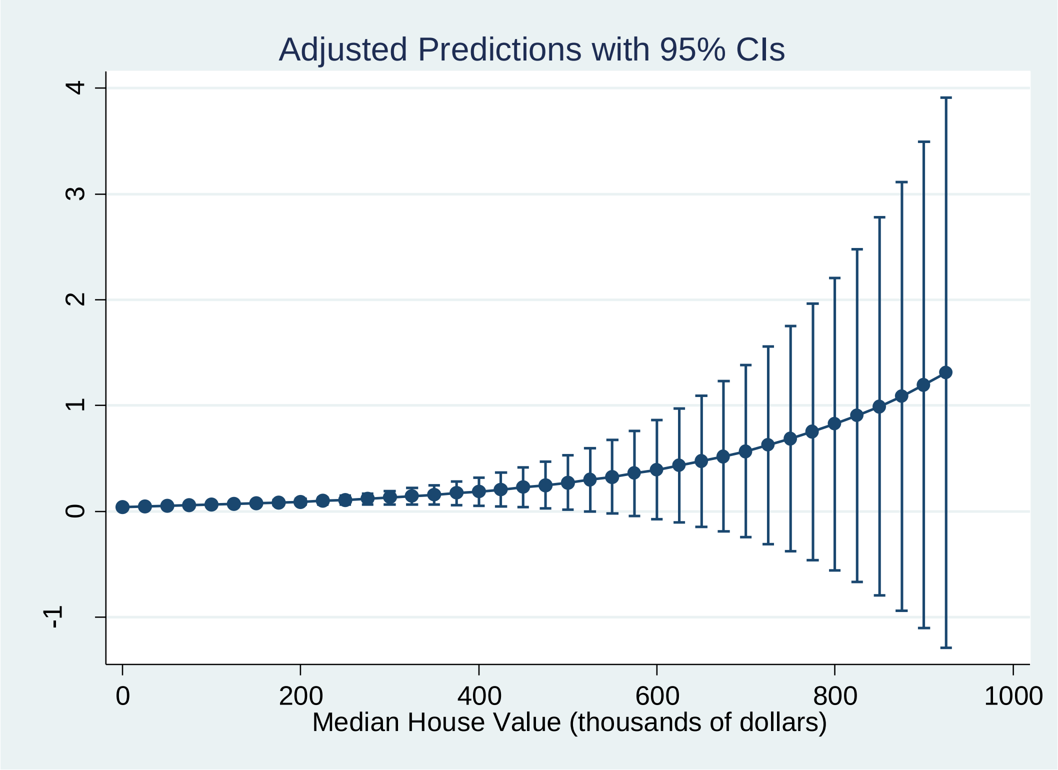

Figure 7. Expected number of events as house value increases, holding all other variables constant at their means (Model 1, NB).

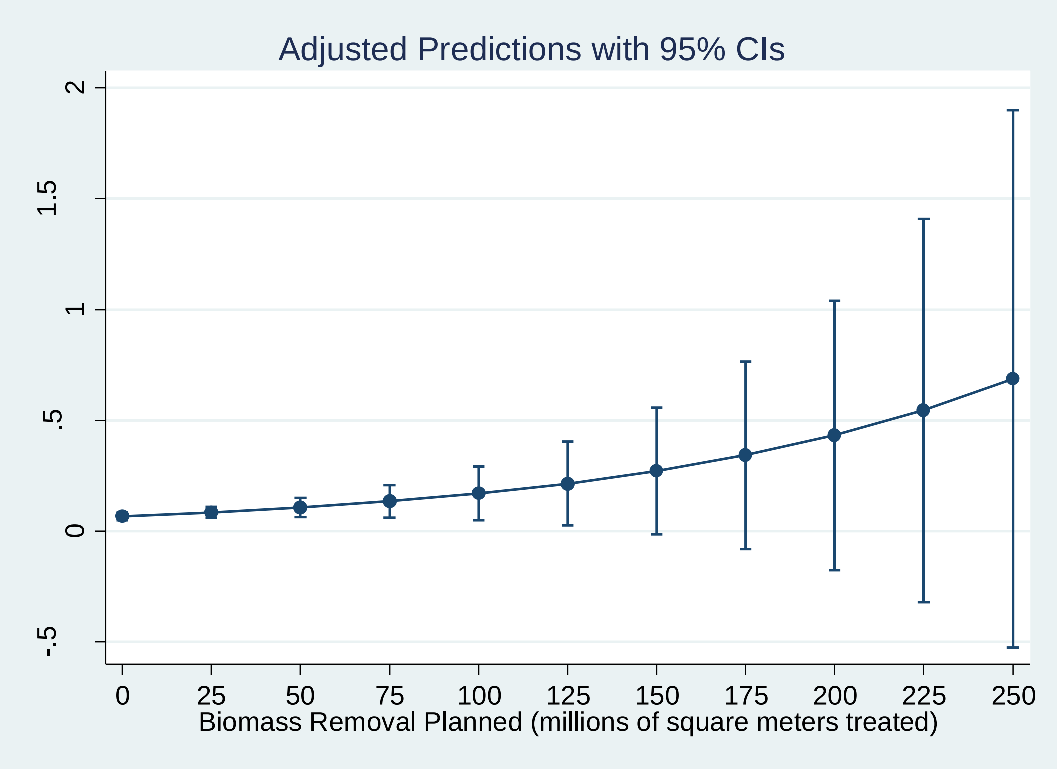

Figure 8. Expected number of events as biomass removal planned increases, holding all other variables constant at their means (Model 1, NB).

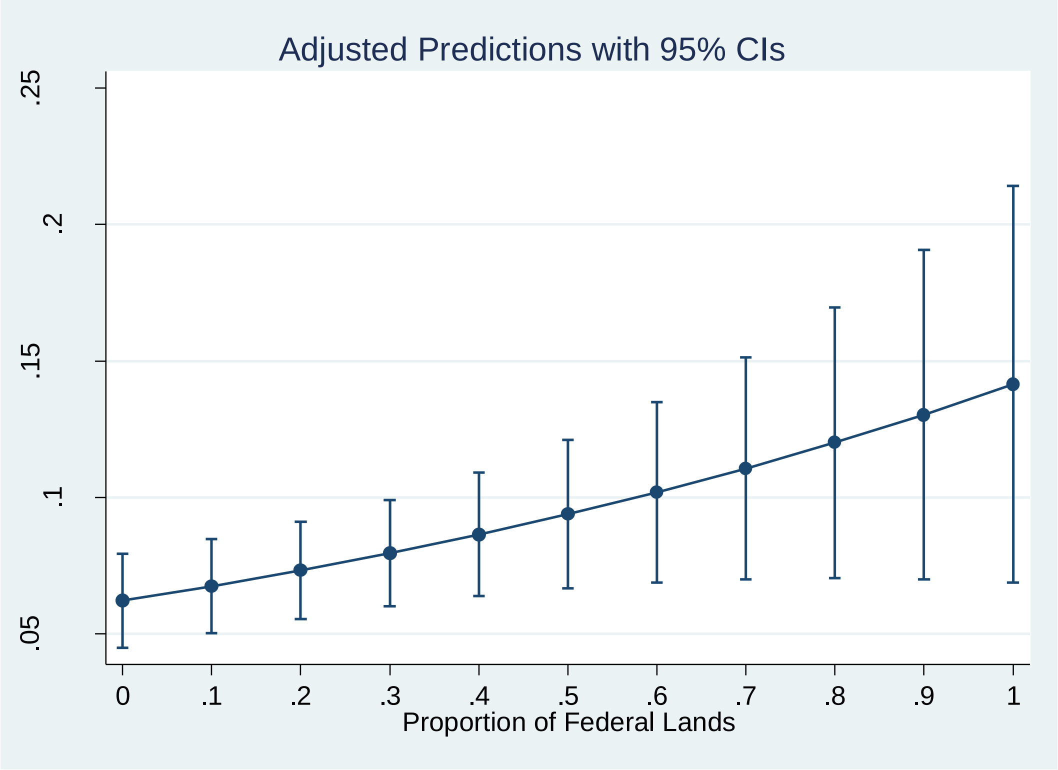

Figure 9. Expected number of events as proportion of Federal land increases, holding all other variables constant at their means (Model 1, NB).

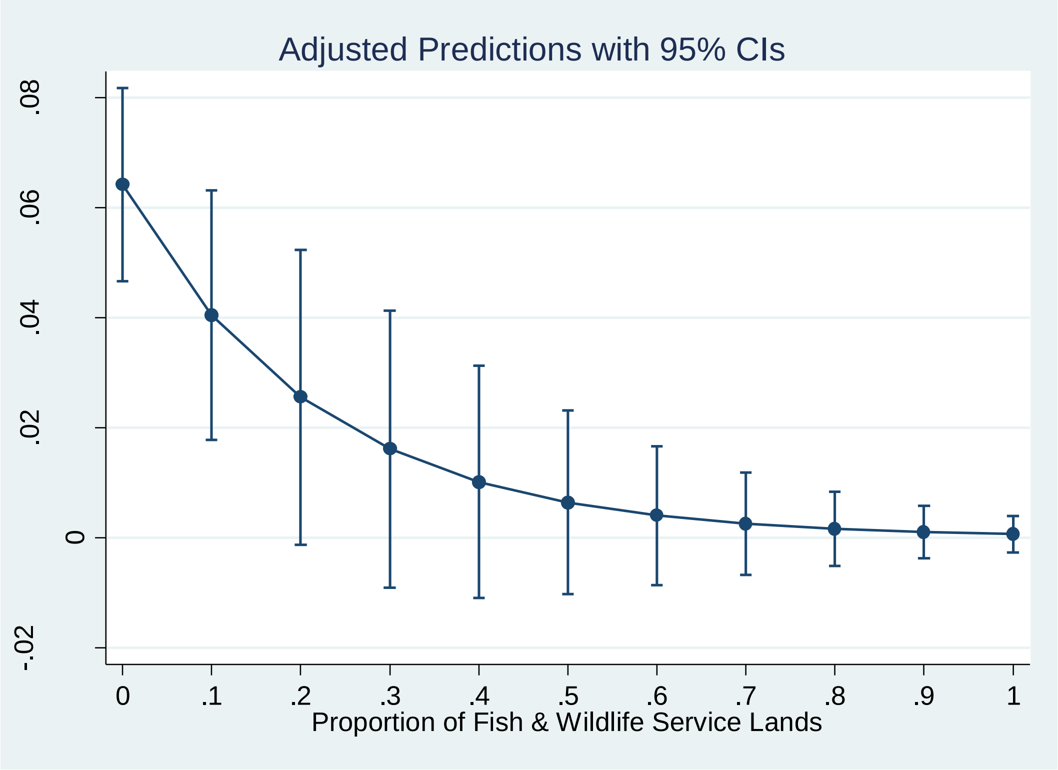

Figure 10. Expected number of events as the proportion of FWS land increases, holding all other variables constant at their means (Model 2, NB).

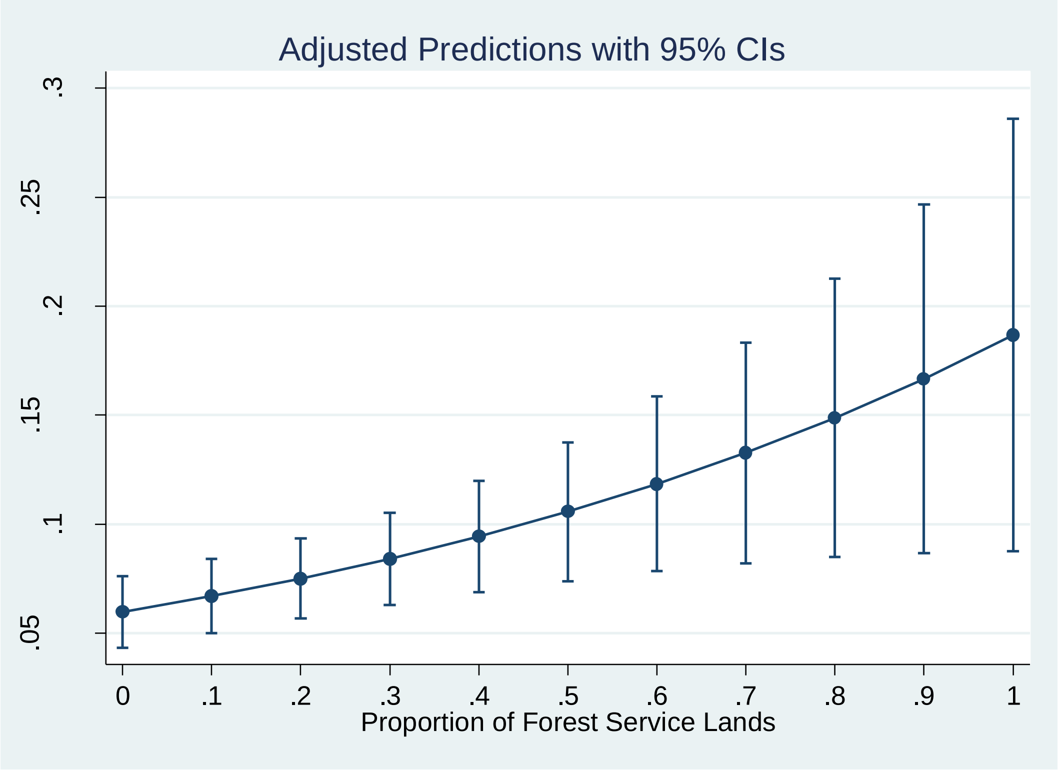

Figure 11. Expected number of events as the proportion of FS land increases, holding all other variables constant at their means (Model 2, NB).

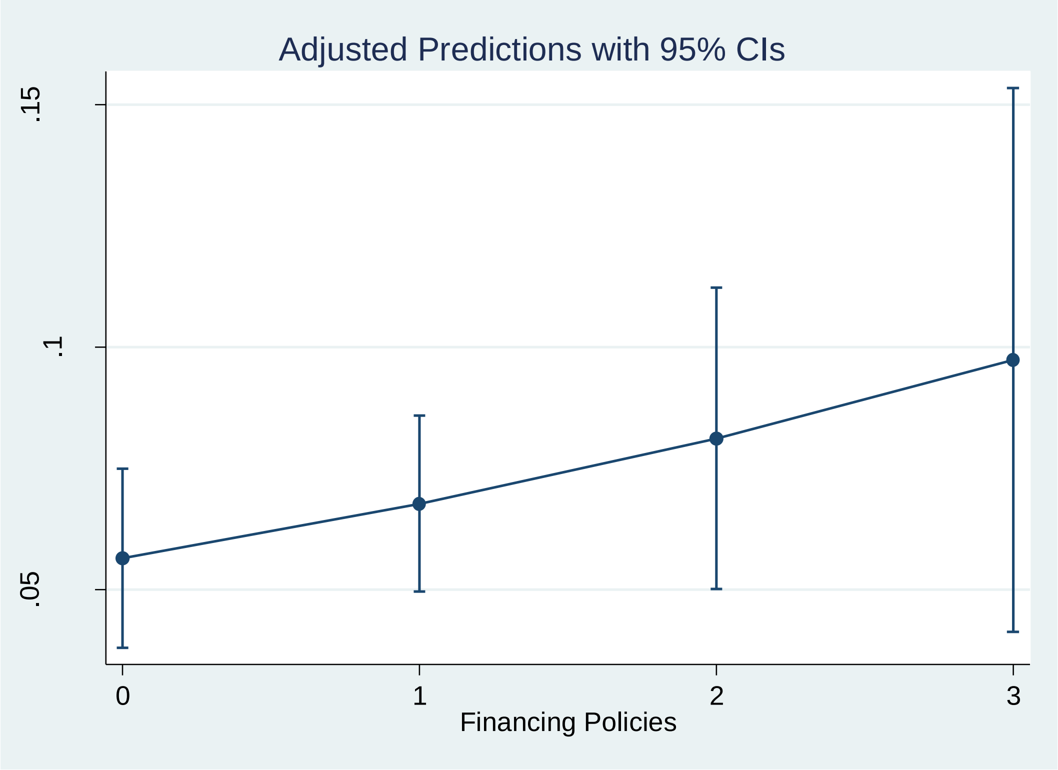

Figure 12. Expected number of events as the number of financing policies increases, holding all other variables constant at their means (Model 3, NB).

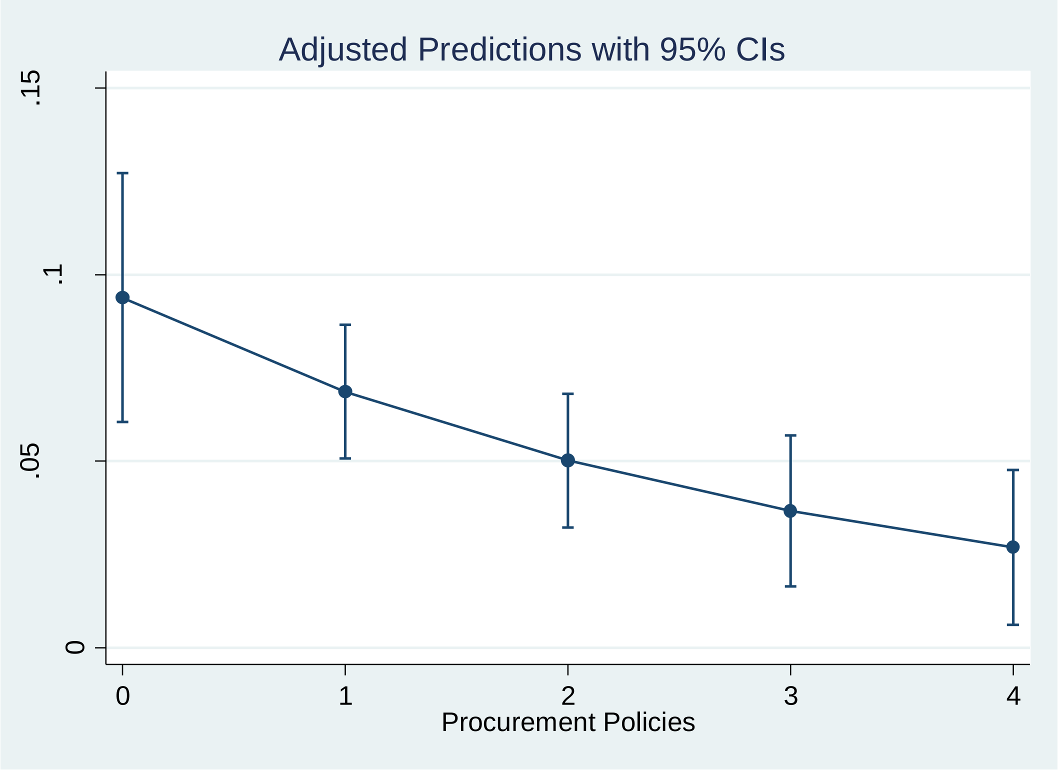

Figure 13. Expected number of events as the number of procurement policies increases, holding all other variables constant at their means (Model 3, NB).

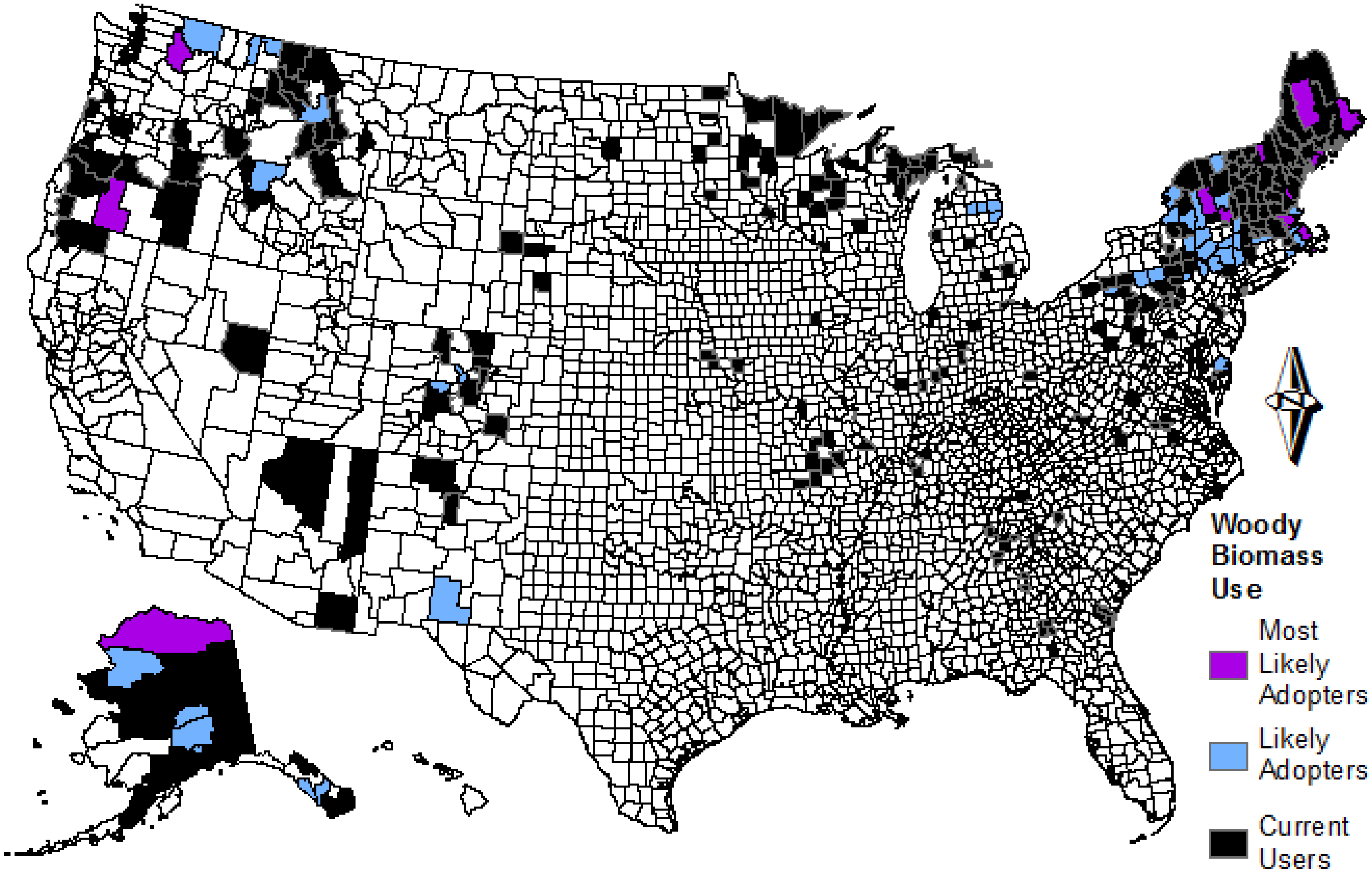

Figure 14. County map of future expansion paths for institutional use of woody biomass as a primary heating fuel based on Model 3. Does not include current users also selected for expansion.

Appendix A: Current users of decentralized woody biomass heat

Counties currently using woody biomass and the number of institutions corresponding to Figure 2.

County, State abbreviation	Institutions	County, State abbreviation	Institutions
Washington County, VT	16	Allen County, IN	2
Aroostook County, ME	11	LaPorte County, IN	2
Chittenden County, VT	11	Vigo County, IN	2
Merrimack County, NH	10	Cumberland County, ME	2
Kennebec County, ME	9	Oxford County, ME	2
Grafton County, NH	8	Waldo County, ME	2
Franklin County, ME	6	Wicomico County, MD	2
Hillsborough County, NH	6	Menominee County, MI	2
Orleans County, VT	6	Boone County, MO	2
Windham County, VT	6	Lincoln County, MT	2
Franklin County, MA	5	Powell County, MT	2
Windsor County, VT	5	Ravalli County, MT	2
Worcester County, MA	4	Sanders County, MT	2
Grant County, OR	4	Rockingham County, NH	2
Franklin County, VT	4	Orange County, NY	2
Orange County, VT	4	Burleigh County, ND	2
Barron County, WI	4	Deschutes County, OR	2
Ketchikan Gateway Borough, AK	3	Harney County, OR	2
Pr. of Wales-Hyder Cen. Area, AK	3	Josephine County, OR	2
Southeast Fairbanks Cen. Area, AK	3	Morrow County, OR	2
Yukon-Koyukuk Census Area, AK	3	Columbia County, PA	2
Larimer County, CO	3	McKean County, PA	2
Androscoggin County, ME	3	Susquehanna County, PA	2
Hancock County, ME	3	Providence County, RI	2
Penobscot County, ME	3	Amelia County, VA	2
Hampshire County, MA	3	Portage County, WI	2
Carroll County, NH	3	Price County, WI	2
Coos County, NH	3	Fairbanks North Star Borough, AK	1
Essex County, NY	3	Kenai Peninsula Borough, AK	1
Franklin County, NY	3	Lake and Peninsula Borough, AK	1
St. Lawrence County, NY	3	Nome Census Area, AK	1
Addison County, VT	3	Valdez-Cordova Census Area, AK	1
Bennington County, VT	3	Apache County, AZ	1
Caledonia County, VT	3	Cochise County, AZ	1
Lamoille County, VT	3	Coconino County, AZ	1
Rutland County, VT	3	Siskiyou County, CA	1
Haines Borough, AK	2	Gilpin County, CO	1
Juneau City and Borough, AK	2	Pueblo County, CO	1
Boulder County, CO	2	Litchfield County, CT	1
Gunnison County, CO	2	Bartow County, GA	1
Jefferson County, CO	2	Brooks County, GA	1
Park County, CO	2	Dade County, GA	1
Routt County, CO	2	Gordon County, GA	1
Liberty County, GA	2	Habersham County, GA	1
Coles County, IL	2	Hall County, GA	1

Appendix A continued. Counties currently using woody biomass and the number of institutions corresponding to Figure 2.

County, State abbreviation	Institutions	County, State abbreviation	Institutions
Haralson County, GA	1	Cook County, MN	1
Long County, GA	1	Hennepin County, MN	1
McIntosh County, GA	1	Koochiching County, MN	1
Pickens County, GA	1	Lake County, MN	1
Polk County, GA	1	Mahnomen County, MN	1
Spalding County, GA	1	Morrison County, MN	1
Tift County, GA	1	Pennington County, MN	1
Turner County, GA	1	Roseau County, MN	1
Upson County, GA	1	St. Louis County, MN	1
Walker County, GA	1	Stevens County, MN	1
Worth County, GA	1	Crawford County, MO	1
Adams County, ID	1	Howell County, MO	1
Benewah County, ID	1	Nodaway County, MO	1
Boise County, ID	1	Ozark County, MO	1
Latah County, ID	1	Perry County, MO	1
Shoshone County, ID	1	Phelps County, MO	1
Grant County, IN	1	Reynolds County, MO	1
Hendricks County, IN	1	Shannon County, MO	1
Jefferson County, IN	1	Texas County, MO	1
Madison County, IN	1	St. Louis city, MO	1
Putnam County, IN	1	Beaverhead County, MT	1
Johnson County, IA	1	Broadwater County, MT	1
Hopkins County, KY	1	Deer Lodge County, MT	1
Lyon County, KY	1	Flathead County, MT	1
Trigg County, KY	1	Granite County, MT	1
Sagadahoc County, ME	1	Mineral County, MT	1
Somerset County, ME	1	Dawes County, NE	1
York County, ME	1	Nemaha County, NE	1
Berkshire County, MA	1	Otoe County, NE	1
Alger County, MI	1	White Pine County, NV	1
Chippewa County, MI	1	Belknap County, NH	1
Delta County, MI	1	Cheshire County, NH	1
Dickinson County, MI	1	Sullivan County, NH	1
Emmet County, MI	1	Rio Arriba County, NM	1
Gogebic County, MI	1	Santa Fe County, NM	1
Houghton County, MI	1	Broome County, NY	1
Ingham County, MI	1	Chemung County, NY	1
Isabella County, MI	1	Fulton County, NY	1
Marquette County, MI	1	Lewis County, NY	1
Mason County, MI	1	Madison County, NY	1
Oakland County, MI	1	Onondaga County, NY	1
Schoolcraft County, MI	1	Queens County, NY	1
Aitkin County, MN	1	Schenectady County, NY	1
Cass County, MN	1	Seneca County, NY	1
Clay County, MN	1	Tioga County, NY	1

Appendix A continued. Counties currently using woody biomass and the number of institutions corresponding to Figure 2.

County, State abbreviation	Institutions	County, State abbreviation	Institutions
Tompkins County, NY	1		
Washington County, NY	1		
Greene County, NC	1		
Lucas County, OH	1		
Ross County, OH	1		
Benton County, OR	1		
Clackamas County, OR	1		
Columbia County, OR	1		
Douglas County, OR	1		
Lane County, OR	1		
Tillamook County, OR	1		
Wallowa County, OR	1		
Adams County, PA	1		
Allegheny County, PA	1		
Bedford County, PA	1		
Bradford County, PA	1		
Bucks County, PA	1		
Cambria County, PA	1		
Centre County, PA	1		
Clearfield County, PA	1		
Crawford County, PA	1		
Elk County, PA	1		
Fayette County, PA	1		
Lycoming County, PA	1		
Northumberland County, PA	1		
Snyder County, PA	1		
Sullivan County, PA	1		
Union County, PA	1		
Warren County, PA	1		
Pickens County, SC	1		
Custer County, SD	1		
Blount County, TN	1		
Grand Isle County, VT	1		
Augusta County, VA	1		
Brunswick County, VA	1		
Franklin County, VA	1		
Nottoway County, VA	1		
Prince Edward County, VA	1		
Raleigh County, WV	1		
Ashland County, WI	1		
Chippewa County, WI	1		
La Crosse County, WI	1		
Sawyer County, WI	1		
Taylor County, WI	1		
Weston County, WY	1		

Appendix B: Marginal effects

Like other binary models the ZI portion of a ZINB model gives coefficients (β) that are in terms of log odds[14], and are easiest interpreted when transformed to odds ratios (ORs) or marginal effects (MEs). For a discussion on ORs refer to Model 1 results. Two competing methods for calculating MEs are Marginal Effects at the Mean (MEM) and Average Marginal Effects (AMEs). While both ME estimates give similar results under the proper assumptions (Bartus, 2005), there are a number of situations that suggest ones use over the other. In the case of large coefficients, large units, or large variances in linear predictions due to underlying heterogeneity within the data the AME is preferred over the MEM (Bartus, 2005; Williams, 2015). In the case of one independent variable being the mathematical transformation of another the MEM is preferred to the AME, while in the presence of multiple indicator variables representing different categories of one underlying independent variable care must be taken when calculating both AMEs and MEM (Bartus, 2005).

In the context of this study I have chosen to use AMEs due to the large units associated with the independent variables in the ZI portion of the model, as well as the large variances of 'Heating Degree Days' and 'Forest Residues' when compared to their respective means (Table 3). In practice the AME is the average of the first partial derivatives for each observation of the ZI model with respect to the corresponding independent variable (Woodridge, 2009). When predicting structural zeros in this study I obtain negative coefficients which result in negative AMEs that are not interpreted in a straightforward manner. Looking at Table B.1, Model 1 'Heating Degree Days' has a AME of -0.023, which indicates that the addition of 1,000 heating degree days is associated with on average a 2.3 percentage point decrease in the predicted probability that the county does not contain an institution with a biomass heating system. In other words as heating degree days increase the probability of an institution using biomass as a primary heating fuel increases. For a visual representation of the probability that a county does not contain an institution using biomass (structural zeros) at representative values of heating degree days refer to the adjusted predictive margins in Figure B.1. Each unit increase in heating degree days has a relatively constant effect on the probability of a structural zero occurring.

Likewise the addition of one person per 1,000,000 m^2 ('Population Density') is on average associated with a 0.005 decrease in the predicted probability that the county does not contain an institution with a biomass heating system. In other words as the population density of a county increases so does the probability of an institution using a biomass heating system. Refer to Figure B.2 for a visual representation of the effect that population density has on the

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[14] β=logarithmic (odds of success/odds of failure)=log(($p_{success}$/(1- $p_{success}$)) / ($p_{failure}$/(1- $p_{failure}$))), where $p_{success}$ is the probability of a structural 0, and $p_{failure}$ is the probability of not being a structural zero (IDRE, 2014d).

predicted probability of structural zeros at representative values. After population density reaches approximately 150 people per 1,000,000 m^2, an additional unit of population density has little to no effect on the probability of a structural zero occurring.

Finally, the addition of 10 million m^3 of ‘Forest Residue’ in a county is on average associated with a 22.6 percentage point decrease in the predicted probability that the county does not contain an institution with a biomass heating system. In other words as forest residue in a county increases so does the probability of an institution using biomass. Refer to Figure B.3 for a visual representation of the affect that forest residue has on the predicted probability of structural zeros. After forest residue reaches approximately 30 million m^3, an additional unit of forest residue has little to no effect on the probability of a structural zero occurring. While the forest residue parameter is statistically significant and vital to modeling structural zeros, as seen in the steep drop off in the adjusted predictive margins in Figure B.3, its interpretation has limited practical and policy implications, in part because in this context most current and future users of woody biomass as a fuel source must be located near a biomass supply, of which institutions use very little as a proportion of total stocks and flows attributed to forest management activities that produce biomass.

Table B.1. Average Marginal Effects (AME) for the ZI portion of ZINB Model 1, Model 2, and Model 3.

Dependent Variable: Institutions	Model 1			Model 2			Model 3		
Independent Variables	AME	Delta Method SE	p-value	AME	Delta Method SE	p-value	AME	Delta Method SE	p-value
Zero Inflated (ZI-Logistic)									
Heating Degree Days	-0.023**	0.010	0.03	-0.030	0.022	0.16	-0.030	0.019	0.12
Population Density	-0.005*	0.003	0.07	-0.005*	0.003	0.08	-0.005*	0.003	0.08
Forest Residues	-0.226***	0.045	0.00	-0.237***	0.066	0.00	-0.233***	0.055	0.00

* $p<0.1$; ** $p<0.05$; *** $p<0.01$

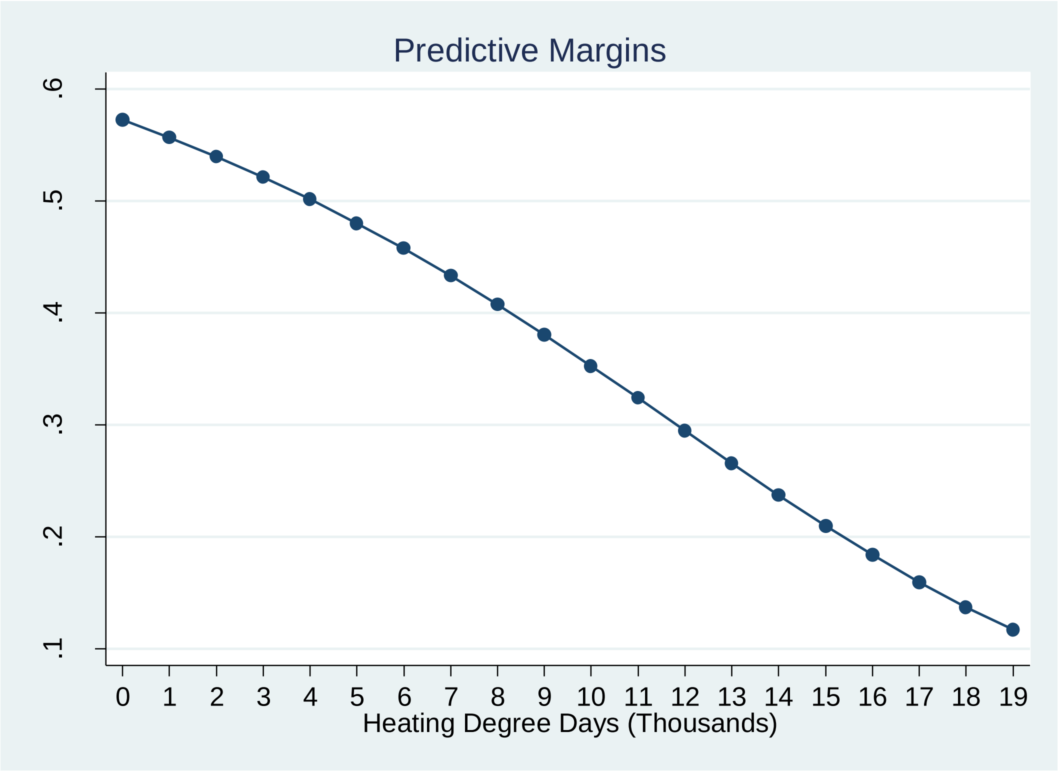

Figure B.1. Probability of structural zeros at representative values of heating degree days (Model 1, ZI).

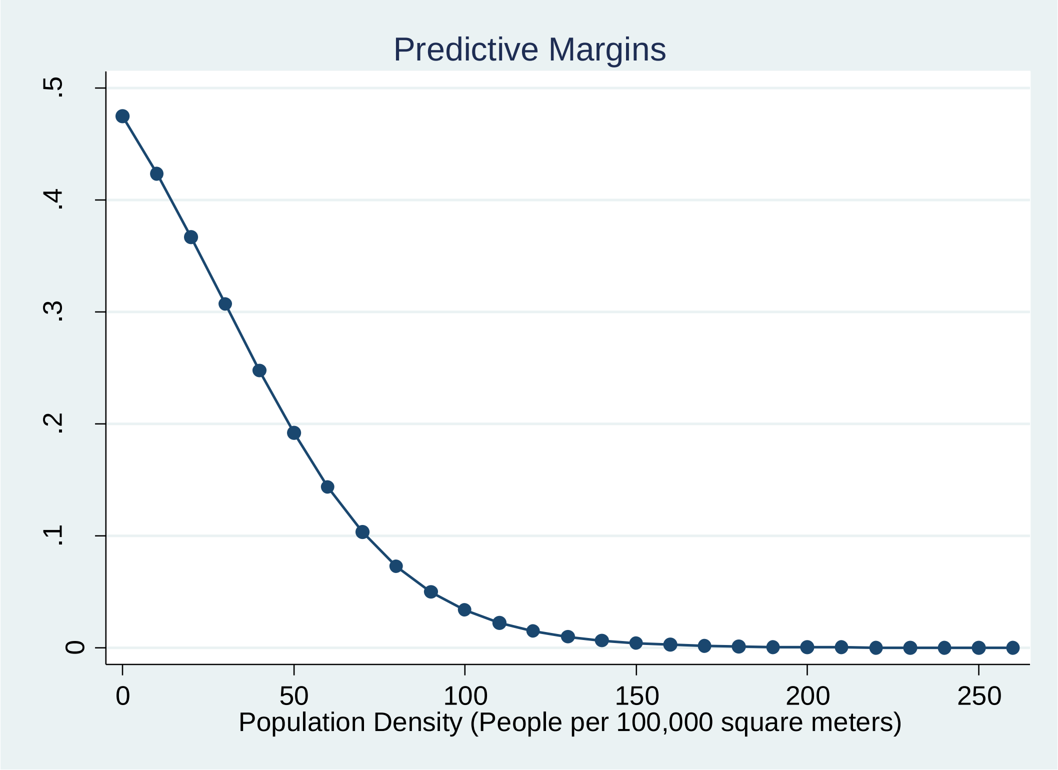

Figure B.2. Probability of structural zeros at representative values of population density (Model 1, ZI).

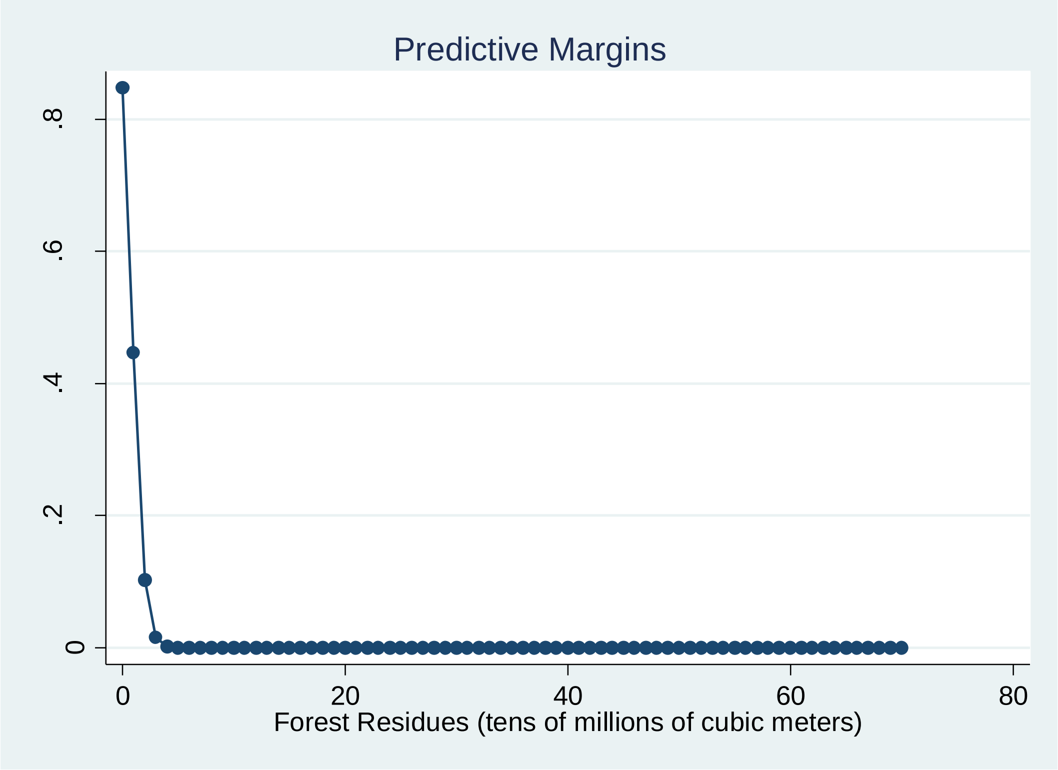

Figure B.3. Probability of structural zeros at representative values of forest residues (Model 1, ZI).

Appendix C: Likely adopting counties

Counties and residuals corresponding to Figure 13, Model 3. Lowest (most likely to adopt) to highest (likely to adopt). This list does not include counties that are currently using decentralized biomass heating systems in U.S. institutions.

County, State abbreviation	Residual	County, State abbreviation	Residual
North Slope Borough, AK	-6.67232	Ulster County, NY	-0.68910
Piscataquis County, ME	-4.73580	Essex County, MA	-0.67982
Washington County, ME	-4.37757	Wayne County, PA	-0.67807
Klamath County, OR	-3.91821	Oneida County, NY	-0.67350
Strafford County, NH	-3.01562	Sullivan County, NY	-0.65978
Lincoln County, ME	-2.76497	Newport County, RI	-0.65692
Knox County, ME	-2.60781	Denali Borough, AK	-0.65432
Chelan County, WA	-2.25532	Otsego County, NY	-0.64070
Nantucket County, MA	-2.22753	Delaware County, NY	-0.63125
Essex County, VT	-1.71544	Rensselaer County, NY	-0.62121
Middlesex County, MA	-1.15410	Iosco County, MI	-0.61162
Hamilton County, NY	-1.09293	Bristol County, RI	-0.60972
Saratoga County, NY	-1.03457	Columbia County, NY	-0.60427
Plymouth County, MA	-1.03340	Tioga County, PA	-0.60261
Dukes County, MA	-1.01592	Norfolk County, MA	-0.59823
Anchorage Municipality, AK	-0.99034	Wyoming County, PA	-0.59469
Warren County, NY	-0.95195	Okanogan County, WA	-0.58293
Forest County, PA	-0.95141	Sussex County, DE	-0.58272
Clinton County, NY	-0.92915	Washington County, RI	-0.57998
Summit County, CO	-0.89417	Oscoda County, MI	-0.56397
Pend Oreille County, WA	-0.88340	Boundary County, ID	-0.55267
Northwest Arctic Borough, AK	-0.81792	Crawford County, MI	-0.55147
Hampden County, MA	-0.80604	Potter County, PA	-0.54696
Pitkin County, CO	-0.78890	Chenango County, NY	-0.54431
Matanuska-Susitna Borough, AK	-0.78262	Alcona County, MI	-0.53907
Otero County, NM	-0.77023	Valley County, ID	-0.51975
Missoula County, MT	-0.75813	Oswego County, NY	-0.51837
Jefferson County, NY	-0.71007	Petersburg Census Area, AK	-0.51662
Dutchess County, NY	-0.70438	Bristol County, MA	-0.50995
Herkimer County, NY	-0.70333	Greene County, NY	-0.50545
Sitka City and Borough, AK	-0.69670		

Appendix D: Spatial structure

To determine the potential presence of spatial autocorrelation (due to spatial autoregression in either the dependent variable or the error term), Global Moran's Index (Moran's I) was calculated with ESRI ArcMap 10.1 (ESRI, 2012) using a row stochastic contiguous method. Moran's I quantifies the strength of interactions between neighboring counties that is indicative of some non-modeled spatial structure in the data (Valcu and Kempenaers, 2010), but does not distinguish between autoregression in the dependent variable (spatial lag) and autoregression in the error term (spatial error). In other words a Global Moran's I tests whether or not the modeled location of institutions using decentralized woody biomass heating systems is spatially random or not. Moran's I takes values between 1 and -1, with the extreme value of 1 signifying perfect positive spatial autocorrelation where residuals for neighboring observations perfectly predict the residual of the current observation. If one's neighbors have positive residuals they will have a positive residual equal to their neighbors' average. The extreme value of -1 signifies perfect negative spatial autocorrelation, where if one's neighbors have positive residuals they will have a negative residual equal to their neighbors' average.

In the context of Model 3, when geographic control variables are omitted Moran's I is 0.152 (p =0.00), which is reduced drastically with the inclusion of the geographic controls to 0.093 (p=0.00). Due to dependent and independent variables that largely take on positive values, a spatial model will have a spatial weights matrix with positive values. As a result, in the case of positive autocorrelation, which is believed to be present in this model, the bias that does occur is expected to be an upward bias in the model coefficients (LeSage and Pace, 2009). In addition, empirical applications often show inefficient coefficients (Musenge et al., 2011).

In addition to including geographic controls to correct for the spatial structure in the data, a number of models were investigated that included spatially lagged independent variables thought to be the cause of the non-modeled spatial structure. All Lagged variables were calculated as an average of variables in neighboring counties. Lagged independent variables investigated include average 'Forest Residues', average 'Biomass Planned' under the NFP, and average 'Proportion of FS' lands of neighboring observations. Lagged independent variables were investigated one at a time and in combination in both model steps separately and simultaneously. Additionally, the lagged variables were investigated as a sum with their non-lagged counterparts. All auxiliary models with lagged independent variables had little effect on the Moran's I estimate or significance when compared to the model with geographic controls only.

Furthermore, a model that included a spatially lagged dependent variable in both the ZI and NB model steps was investigated (Table D.1). Inclusion of the spatially lagged dependent variable reduces Moran's I to 0.005, and was not statistically significant (p = 0.61). However, the inclusion of a lagged dependent variable introduces endogeneity bias into the model and affects the coefficients that are sufficiently trended across space (Achen, 2000). Simultaneity is at the heart of the matter when spatially lagged Y is included in the right hand side—Y_i is a function of Y_j and Y_j is a function of Y_i.

In the context of this research the inclusion of lagged dependent variables appears to significantly reduce spatial structures in residuals as quantified by Moran's I. However, there is a high risk that serious bias has been injected into model coefficients with the inclusion of lagged dependent variables, because I have not dealt with the endogeneity of the spatially lagged dependent variable. Currently available statistical code does not facilitate modeling spatial lag and spatial error terms for zero inflated models and is left for future work (Fortenbery, 2013). While this model with the lagged dependent variables affects some coefficient estimates, it predicts 92.04% of county counts correctly within 0.499 of the actual count, which is very similar to the 91.82% in Model 3 (Table D.1). Even though the inclusion of lagged dependent variables may have injected serious bias into the model coefficients, it is interesting to note that many of the counties where efforts encouraging biomass heating systems are likely to be most effective have not changed. Refer to Figure D.1 and Table D.2 for an expansion map and list of likely adopters not currently containing an institution using a decentralized woody biomass heating system.

Recent empirical evidence suggests that in the presence of properly modeled excess zeros the additional modeling of spatial structures tends to result in very little gained. For example, an industry location study of biodiesel refineries in the contiguous U.S. found evidence of a spatial structure in the response as measured by Moran's I, while the spatial logit and tobit models accounting for the spatial error resulted in coefficient estimates that were qualitatively unchanged and spatial error coefficients that were statistically insignificant (Fortenbery et al., 2013). It was concluded that non-spatial models had stable results when compared to their spatial counterparts, possibly due to the adequate capture of spatial dependency with independent variables (Fortenbery et al., 2013) a phenomenon that may be further supported by the zero inflated modeling structure as well. A study by Musenge et al. (2011) on the determinants of human immunodeficiency virus (HIV) and tuberculosis (TB) mortality for zero inflated data presented nearly identical significance levels of coefficients when comparing non-spatial ZINB models to a ZINB model that allows for spatial random effects. Nevertheless advantages of modeling the spatial structure include removing bias from model coefficients (LeSage and Pace, 2009), and, as seen in application, gaining efficiency in standard error calculations (Musenge et al. 2011). In the context of our study there is less concern about efficiency gains because these have most likely been overcome by a large sample size. Additionally, this study has controlled for much of the spatial structure by controlling for geographic location with latitude, longitude and regional indicator variables.

For the reasons listed above more advanced spatial models were not considered any further. Moreover, the significance of the Moran's I in Model 3 may be, in part, driven by the large sample size, which would drive down standard error calculations and increase p-values as an artifact of the modeling process.

Table D.1. Results for the Zero Inflated Negative Binomial (ZINB) Model 3 and Model 3 with a lagged dependent variable in both model sections.

Dependent Variable: Institutions	Model 3				Model 3 with Lagged Avg. Dep. Var.			
Independent Variables	Coef	[OR] (IRR)	Robust SE	p-value	Coef	[OR] (IRR)	Robust SE	p-value
Zero Inflated (ZI-Logistic)								
Avg. Neighboring Ins.					-16.026***	[0.000]	5.946	0.01
Heating Degree Days	-0.255	[0.775]	0.190	0.18	-0.472***	[0.624]	0.145	0.00
Population Density	-0.043*	[0.957]	0.026	0.10	-0.671	[0.511]	0.770	0.38
Forest Residues	-2.009***	[0.134]	0.751	0.01	-0.030	[0.971]	0.045	0.52
_cons	3.012**		1.312	0.02	4.168***		0.887	0.00
Negative Binom (NB-Count)								
Avg. Neighboring Ins.					0.215**	(1.240)	0.099	0.03
Heating Degree Days	0.138	(1.148)	0.104	0.18	0.051	(1.053)	0.086	0.55
Natural Gas Prices	0.256***	(1.291)	0.063	0.00	0.240***	(1.271)	0.070	0.00
House Value	0.002*	(1.002)	0.001	0.07	-0.000	(1.000)	0.001	0.88
Forest Residues	0.002	(1.002)	0.007	0.77	0.016*	(1.016)	0.008	0.06
Biomass NFP	0.012**	(1.012)	0.005	0.01	0.016***	(1.017)	0.006	0.00
Proportion NPS	-2.180	(0.113)	1.572	0.17	-1.404	(0.246)	1.266	0.27
Proportion FWS	-4.606*	(0.010)	2.671	0.08	-3.983*	(0.019)	2.194	0.07
Proportion FS	1.082***	(2.951)	0.303	0.00	1.172***	(3.230)	0.317	0.00
Proportion DOD	1.690	(5.420)	2.846	0.55	3.158	(23.524)	2.097	0.13
Proportion BOR	-8.094	(0.000)	28.619	0.78	-6.405	(0.002)	32.413	0.84
Proportion BLM	-0.719	(0.487)	1.194	0.55	-1.936	(0.144)	1.264	0.13
Proportion BIA	-0.361	(0.697)	0.936	0.70	-0.697	(0.498)	1.126	0.54
Cost Share Grants	-0.103	(0.902)	0.095	0.28	-0.052	(0.949)	0.088	0.56
Technical Assistance	-0.007	(0.993)	0.067	0.92	0.033	(1.034)	0.068	0.63
Financing	0.181	(1.199)	0.120	0.13	0.153	(1.165)	0.116	0.19
Procurement	-0.313**	(0.731)	0.124	0.01	-0.247**	(0.781)	0.117	0.04
Rules and Regulations	0.047	(1.048)	0.084	0.58	0.011	(1.011)	0.085	0.90
Tax Incentives	-0.044	(0.957)	0.039	0.26	-0.032	(0.968)	0.044	0.47
Population	0.017	(1.017)	0.029	0.57	0.027	(1.027)	0.025	0.29
Road Density	-1.081	(0.339)	0.659	0.10	-1.784***	(0.168)	0.624	0.00
Port Capacity	-0.012	(0.988)	0.008	0.11	-0.006	(0.994)	0.009	0.46
County Area	0.004	(1.004)	0.003	0.11	0.007***	(1.007)	0.002	0.00
Latitude	0.012***	(1.012)	0.003	0.00	0.009***	(1.009)	0.003	0.00
Longitude	0.009***	(1.009)	0.002	0.00	0.007***	(1.007)	0.002	0.00
West Coast	0.880	(2.410)	1.238	0.48	-0.753	(0.471)	1.256	0.55
South	0.605	(1.832)	0.446	0.17	0.603	(1.828)	0.458	0.19
Lake States	1.386***	(4.000)	0.439	0.00	0.450	(1.568)	0.444	0.31
Northeast	1.495***	(4.458)	0.488	0.00	0.500	(1.649)	0.493	0.31
Northwest	2.259***	(9.577)	0.726	0.00	1.022	(2.779)	0.765	0.18
Midwest	1.615***	(5.030)	0.425	0.00	0.424	(1.528)	0.513	0.41
Southwest	3.778***	(43.708)	0.663	0.00	1.844**	(6.324)	0.766	0.02
_cons	-7.530***		0.990	0.00	-5.368***		1.051	0.00
lnalpha _cons	-0.601		0.371	0.10	-0.228		0.253	0.37
N	3142				3142			
Log Likelihood	-781.86				-766.11			
Chi Square	560.35			<0.0001	266.86			<0.0001
% correctly predicted ± 0.499 residual	91.82%				92.04%			

Table D. 2. Counties and residuals corresponding to Figure D.1, Model 3 with lagged average dependent variable. Lowest (most likely to adopt) to highest (likely to adopt). This list does not include counties that are currently using decentralized biomass heating systems in U.S. institutions.

County, State abbreviation	Residual	County, State abbreviation	Residual
Klamath County, OR	-17.67811	Warren County, NY	-0.67485
Piscataquis County, ME	-12.60434	Idaho County, ID	-0.67318
Washington County, ME	-10.21173	Bristol County, RI	-0.66314
Essex County, VT	-3.49396	Boundary County, ID	-0.65019
Strafford County, NH	-2.52182	Skagway Municipality, AK	-0.63861
Lincoln County, ME	-2.02723	Norfolk County, MA	-0.62616
North Slope Borough, AK	-1.98276	Herkimer County, NY	-0.61221
Knox County, ME	-1.73188	Bryan County, GA	-0.60399
Wrangell City and Borough, AK	-1.68344	Northwest Arctic Borough, AK	-0.60199
Clinton County, NY	-1.51379	Denali Borough, AK	-0.59366
Petersburg Census Area, AK	-1.31399	Bristol County, MA	-0.58641
Forest County, PA	-1.02597	Ontonagon County, MI	-0.57388
Chelan County, WA	-0.97852	Potter County, PA	-0.55720
Anchorage Municipality, AK	-0.96396	Hoonah-Angoon Census Area, AK	-0.55499
Hamilton County, NY	-0.90691	Newport County, RI	-0.54068
Middlesex County, MA	-0.89572	Tioga County, PA	-0.53603
Hampden County, MA	-0.87685	Saratoga County, NY	-0.52738
Summit County, CO	-0.86999	Cleburne County, AL	-0.51665
Navajo County, AZ	-0.73672	Itasca County, MN	-0.51567
Jefferson County, NY	-0.73184	Jackson County, CO	-0.51100
Grand County, CO	-0.73140	Valley County, ID	-0.50832
Missoula County, MT	-0.72588	Lake County, MI	-0.50805
Union County, OR	-0.71556	Jefferson County, OR	-0.50576
Essex County, MA	-0.70191	Gilmer County, GA	-0.50537
Kent County, RI	-0.69261	Cameron County, PA	-0.50388
Matanuska-Susitna Borough, AK	-0.69251		

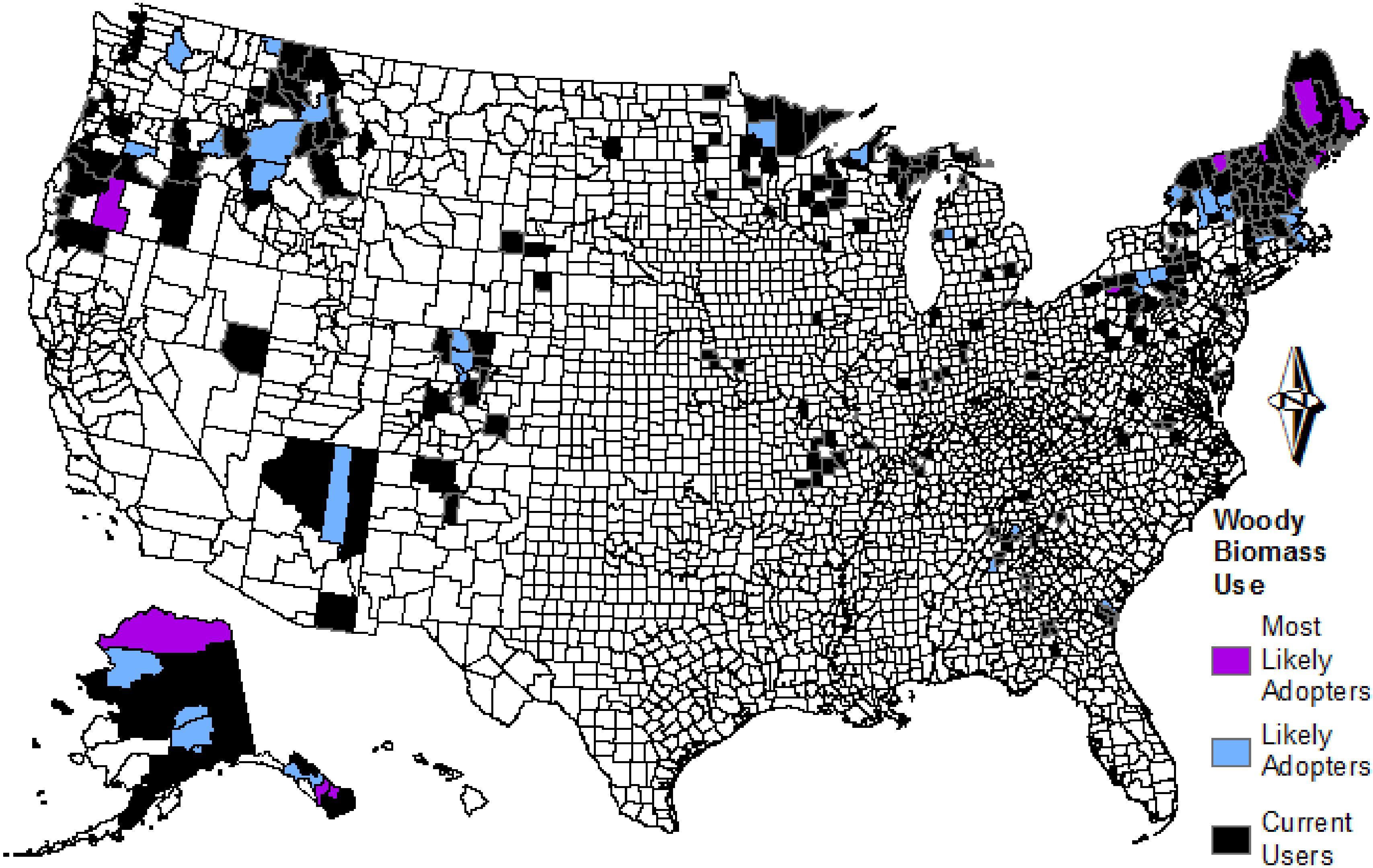

Figure D.1. County map of future expansion paths for institutional use of woody biomass as a primary heating fuel based on Model 3. Does not include current users also selected for expansion.

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