School of Energy Resources
Center for Energy Regulation & Policy Analysis

NUCLEAR SERIES PART 2

WYOMING'S NUCLEAR SUPPLY CHAIN OPPORTUNITIES AND CHALLENGES: COMPONENT MANUFACTURING

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ACKNOWLEDGMENTS

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SER collaborates with stakeholders at the state, national and international levels to advance energy technologies and policies to grow and support Wyoming's robust energy sector. SER's mission is to promote energy-driven economic development for the state, and it leads the University of Wyoming's talent and resources for interdisciplinary research and outreach, fulfilling Wyoming's promise to be a global leader in a thriving and sustainable energy future.

Contents

Contents

Abbreviations

AMT	Advanced manufacturing Technologies
ASME	American Society of Mechanical Engineering
BWXT	Babcock and Wilcox Nuclear Technologies
CERPA	The University of Wyoming, School of Energy Resources Center for Energy Regulation and Policy Analysis
CFR	Code of Federal Regulations
CNC	Computer numerical control machines
DOE	Department of Energy
DiD	Difference in difference
EIA	Energy information administration
GE	General Electric
IAEA	International Atomic Energy Agency
LWR	light water reactor
NDE	Non-destructive examination
NRC	Nuclear Regulatory Commission
NSSS	Nuclear stem supply systems
QA	Quality assurance
SR	Safety related
SMR	Small modular reactor
SSC	Structure, system, and component
WH	Westinghouse
WEA	Wyoming Energy Authority

Tables

Tables

Figures

Figures

EXECUTIVE SUMMARY

This report quantifies the economic outcomes of fostering a nuclear component manufacturing industry in Wyoming. The unique challenges and opportunities of attracting the industry to Wyoming are identified. Additionally, an event study is performed that estimates economic outcomes under a range of future nuclear power development paths.

The analysis importantly concludes that there is potential to establish a nuclear component sector in Wyoming. Small nuclear components can be manufactured in the State without significant changes to legal or economic conditions. Developing infrastructure for large nuclear components is more difficult, requiring significant State support to progress.

This report is one of a series evaluating the feasibility of developing an integrated nuclear sector in Wyoming. From the mine mouth to spent fuel processing, each step in the nuclear supply chain has unique economic challenges. To compare the opportunities for Wyoming across the nuclear supply chain, a qualitative scoring system of advantages and obstacles is applied (Gebben & Peck, 2023). The summary of these scoring criteria for nuclear component manufacturing is provided in Table 1.

Table 1:
Significant Economic Factors Related to Wyoming Nuclear Component Manufacturing

Small Components

	Level	Summary
Economic	Minor Obstacle	Shift to foreign manufacturing.
Existing Industries	Moderate Advantage	Existing Wyoming manufacturing sector.
Tax Structure	Major Advantage	Tax exemption for manufacturing equipment.
Location	Minor Obstacle	Cold weather consideration. No nuclear power produced.
Legal	Minor Obstacle	Added cost of compliance varies by part.
Technology	Minor Obstacle	Existing advanced manufacturing methods can increase growth.
Overall Score	Minor Advantage	Incentives for manufacturing. No major barriers.

Large Components

	Level	Summary
Economic	Major Obstacle	Large economies of scale. U.S. nuclear manufacturing decline.
Existing Industries	Major Obstacle	No domestic forges can produce the largest generation III components.
Tax Structure	Major Advantage	Tax exemption for manufacturing equipment.
Location	Minor Obstacle	Cold weather consideration. No nuclear power produced.
Legal	Moderate Obstacle	Major added cost to manufacturing.
Technology	Major Obstacle	Advances in reactor design and manufacturing technology affects future.
Overall Score	Major Obstacle	Large economies of scale required.

The scores are segregated between large components and small components because the economic obstacles of each manufacturing type are distinct. There are incentives for small component manufacturing firms to locate in Wyoming, including tax rates and an existing energy component manufacturing sector. However, there are significant obstacles to developing large components in the U.S. and, consequently, in Wyoming. Industrial manufacturing has shifted overseas since the peak of nuclear power plant construction in the 1970s. Currently, there are no forges in the U.S. large enough to accommodate the construction of the major components for the largest commercial nuclear power plants[1]. The overall score for the large components is set by the most significant obstacles, namely the limits on manufacturing capacity for ultra large Generation III reactor components, and the economies of scale required for this production. There are no *major obstacles* to establishing small component manufacturing in Wyoming, the overall score of small components reflects the average of the categorical scores.

Table 2 shows the projected economic benefits that nuclear component manufacturing would bring to Wyoming under various forecasts of nuclear plants installation by 2050. The numeric results are derived from an input-output economic model assuming a reference design of reactors.

Table 2:
Economic Impacts

Nuclear Power Demand Scenario	**Low**	**Middle**	**Mid-High**	**High**
Jobs (Person-Years)	0	800	1,600	14,100
Tax Revenue[2] (Mill. USD)	0	$3.5	$7.1	$61.5
Social Benefits	None	Industry colocation		
Social Costs	No major environmental, or social costs			

1 Such as AP1000 components requiring ultra large forging.
2 Total State and County revenue accrued by 2050, including both direct and induced effects.

The benefits are constrained by the expectation of future nuclear reactor production. Most current economic forecasts predict a retraction of nuclear power in the U.S. by 2050 (Energy Information Administration, 2023b; International Atomic Energy Agency, 2022a). However, if technological development lowers nuclear power plant capital costs models predict that 42 new nuclear projects can be added in the U.S. to replace retiring power plants[3].

While the direct benefits of nuclear component manufacturing are lower than the previously studied uranium enrichment sector, the barriers to entry are minimal and the non-monetary benefits come without significant social costs. The indirect benefits include promotion of a local nuclear economy, continued technological development, and financial diversification of existing Wyoming industry.

[3] Based on the EIA Annual Energy Outlook, assuming a 40% decline in production costs by 2050(Energy Information Administration, 2023a). 42 projects include both SMR and advanced reactors to fill capacity. See Section 4.3 for analysis details.

INTRODUCTION

Wyoming is critical for the U.S. energy economy, producing the third most energy of any state (Energy Information Administration, 2022b). The prominence of Wyoming as an energy supplier has generated interest in adding nuclear produced electricity to the States' portfolio. Recent nuclear projects in Wyoming include plans for an advanced reactor in Kemmerer (DOE Office of Clean Energy Demonstrations, n.d.), State funding for research of micro-reactors with industrial applications (BWX Technologies, 2023), regional collaboration between Idaho and Wyoming to develop nuclear technology (U.S. Economic Development Administration, 2023a), and Wyoming based L&H Industrial's entrance into the nuclear component market (L&H Industrial, 2023). For nuclear power plant projects to mature, nuclear components must be supplied by manufacturers. This report studies the opportunities, challenges, and benefits of developing this nuclear component manufacturing sector in Wyoming.

The University of Wyoming, School of Energy Resources Center for Energy Regulation and Policy Analysis (CERPA) completed a series of interdisciplinary economic analyses evaluating the opportunities and challenges for Wyoming economic development in the nuclear sector. The series successively evaluates the economic conditions of each segment of the nuclear supply chain, from uranium mining, all the way to spent fuel storage. This report is the second in the series focused on nuclear component manufacturing. These economic analyses were produced to provide the Wyoming Legislature, other policy makers, stakeholders, and the general public with objective evaluations of new investment opportunities within the State.

This white paper begins with a summary of the nuclear component market, the demand for these components, and the existing supply-chain. The paper identifies supply-chain market structures that may provide new opportunities in Wyoming. Then, the benefits of establishing a nuclear components industry in Wyoming are estimated in terms of employment, tax revenue, and non-monetary considerations.

BACKGROUND

Nuclear component manufacturing is a key link in the nuclear power supply chain. The parts needed to construct a nuclear power plant are diverse. Some components have analogous counterparts in other industries, such as valves, pipes, and electronics systems, while others are highly specialized for nuclear power plants. The materials and tolerance of components vary widely based on the reactor design[4]. There are more than one hundred component categories for a baseline advanced nuclear power plant (Energy Information Administration, 2020; Venneri, 2021/2023)[5]. This upstream component manufacturing industry significantly affects the downstream profitability of nuclear power plants. Recent cost overruns at the Vogtle nuclear power plants in Georgia were partially attributed to delays in component manufacturing using modular fabrication within required design specifications (Eash-Gates et al., 2020; Lovering et al., 2016).

Given the diversity of components manufactured for the nuclear industry, it is useful to classify the types of parts into three categories. Parts classification can take an engineering, legal or economic perspective. Each method of classification provides insights into the feasibility of Wyoming nuclear components manufacturing in Wyoming. An engineer may classify nuclear components within a system that accomplishes specific tasks for the operation of the nuclear power plant. Elements of a nuclear power plant are identified by structure, system, and component (SSC). Components are the smallest unit of measure and can include a length of pipe or valve. Structures include elements that support operations, such as buildings, tanks, and basins. A system is defined as a collection of components or structures assembled to perform a function (Ruocco, 2011). Each component is classified within a system. For example, the nuclear steam supply

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4 For example, a TerraPower SMR design requires a HT0 duct which requires unique materials and manufacturing capability (Kinsey et al., 2018)

5 See Appendix (B)

system encompasses all components that are a part of the main steam control system. This includes the primary coolant pump, steam generators, and drive pumps[6]. For a complete list of component categories and the associated parts see Appendix (B) Table 16.

Legal classifications of components are based on operational safety standards. The Nuclear Regulatory Commission (NRC) uses three distinct categories of SSC's: safety related, important to safety, and industrial grade. Safety related (SR) SSCs are identified as being required for a nuclear power plant to safely operate[7]. Significant to safety, SSC's provide defense-in-depth to the nuclear power plant. These include redundant safety features such as supplemental power. The industrial grade category captures any part that is used for non-nuclear applications. For example, turbine generators and water pumps are industrial grade when applied to power generation and not nuclear reactor safety[8]. These legal classifications affect the costs connected to regulatory compliance, with safety related components requiring extensive quality assurance standards. This results in the need for precise manufacturing equipment to be used in production. See Section 3.6 for more information about SR SCC regulatory standards and certification.

For economic analysis centered on supply, components are aggregated into categories of small or large. These classifications are based on the characteristics of companies producing the components. Large nuclear components require specialized forges and cannot be easily produced by existing U.S. firms. Large components also have logistical considerations for transportation and installation. Examples of large components include reactor vessels, steam generators, containments, and turbine rotors. On the other hand, small components can be produced in part with non-specialized manufacturing equipment. For example, computer numerical control machines (CNC), forges, lathes, and welding equipment can be used to produce parts unrelated to the nuclear industry[9]. Even though the small components are not interchangeable at the nuclear power plant, they are a single product from the supplier's perspective. These manufacturing facilities produce "parts" so the sale of a $1000 component to a nuclear power plant is the same as selling

[6] Some common systems and categories used are: Pneumatic systems, nuclear steam supply systems, emergency systems, fuel handling and storage, heat rejection systems, turbine equipment.

[7] From 10 CFR 50.2 A safety related SSC must ensure one of the following (1) The integrity of the reactor coolant pressure boundary (2) The capability to shut down the reactor and maintain it in a safe shutdown condition; or (3) The capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures comparable to the applicable guideline exposures set forth in § 50.34(a)(1) or § 100.11 of this chapter, as applicable.

[8] Most of these components are highly specialized, only manufactured by a few well-established suppliers. For example, almost all domestic nuclear power plants use either a Westinghouse (WH) or General Electric (GE) power conversion system (turbine-generator). Specialized vendors also provide turbine auxiliaries; feedwater, condensate, and circulation water pumps; feedwater heaters, motor-operated valves; high, medium, and low voltage electrical switchgear; high voltage transformers, and condenser cooling water system.

[9] Even when equipment is specialized, over a long enough timeframe, existing manufacturers can switch production between any small components based on market conditions.

any other $1000[10] part. Examples of small components include valves, switchgears, and piping. Because the supply function of small components is more responsive to industry changes than large components, it is necessary to analyze the two independently.

These three parts classifications are used in different contexts. For analysis of the economic barriers to production economic classifications are used because the response of small component companies is similar enough to be modeled as a single market. However, discussing demand factors, the engineering categorizations are more important because the legal classifications create different incentives for component manufacturers. Safety related components accrue additional costs due to quality assurance standards. This creates distinct supply considerations for producing safety related components addressed in Section 3.6.

2.1 NUCLEAR MANUFACTURING DEMAND FACTORS

The demand for nuclear components is directly intertwined with nuclear power plant and Small Modular Reactor (SMR) construction. This can be compared to other segments of the nuclear supply chain which have more flexibility. For example, uranium enrichers can underfeed the centrifuges in response to uranium price changes (Meade & Supko, 2015), but nuclear components are only constructed to maintain existing nuclear power plants, or to add new nuclear capacity to the electric grid. Further, for the quantity of parts demanded to increase, new facilities must be constructed. Maintaining the existing fleet of nuclear power plants, as has been the status quo in the U.S. for 30 years, does not induce significant growth in the components manufacturing sector[11].

The dynamic is more complicated over the long term. The number of power plants constructed depends on the cost of nuclear power production and the cost comparison to other electricity resources[12]. Traditional nuclear designs are the highest capital cost electric source, so the long-term competitiveness of nuclear power is endogenously determined with manufacturing costs (Energy Information Administration, 2022b; Rothwell, 2018). A reduction in manufacturing costs of components will increase the long-term expected number of power plants (quantity demanded of components). There is also technical substitution since reactor designs can reduce the number of manufactured parts, making modern designs that employ passive safety features and smaller footprints appealing[13].

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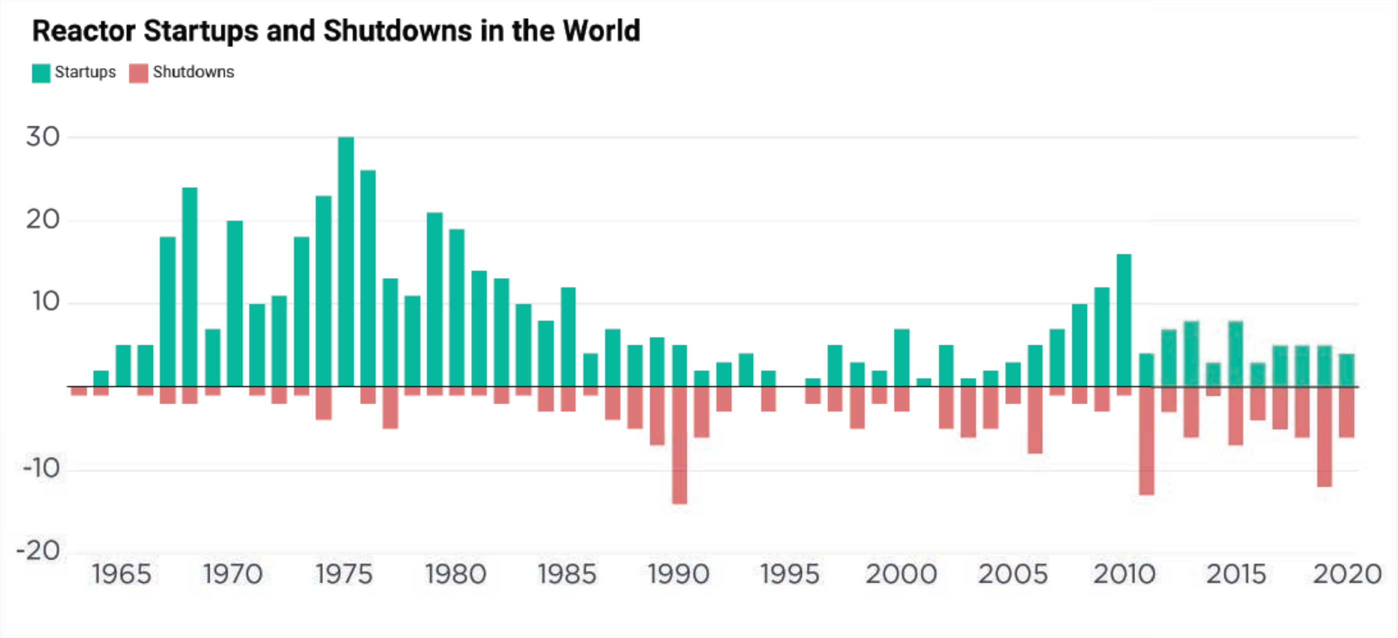
10 Assuming identical production costs.
11 There remains a source of demand from older power plants as replacement parts are needed.
12 Wind, natural gas, and coal are currently the major cost competitors.
13 A major cost advantage from reducing the number of components comes from reduced legal costs. Fewer parts require quality assurance controls meeting NRC standards.

The manufacturing methods required for large scale nuclear power plants differ from small modular reactors. For this reason, the trends in demand are provided separately for each design type. The global number of traditional nuclear reactors added to the electric grid has declined significantly from a peak rate of 30 per year in 1975 to only four per year in 2020 (Figure 1).

Figure 1:
Change in Global Number of Active Reactors[14]



Contributing to this trend was the cost reduction of electric generation alternatives, such as natural gas and the significant increase of nuclear construction costs since the 1970's (Lovering et al., 2016). Without new capacity added to the electric grid, the only market for components is in maintenance and replacement.

SMRs, including micro-reactors[15], have emerged as new distinct markets for component manufacturing (Nuclear Regulatory Commission, 2023c)[16]. These designs significantly reduce the overall construction cost per facility, although the capital intensity is higher than traditional designs (Energy Information Administration, 2020). The compact structure of SMR's allows large components to be built offsite and shipped to a location at lower cost than traditional designs.

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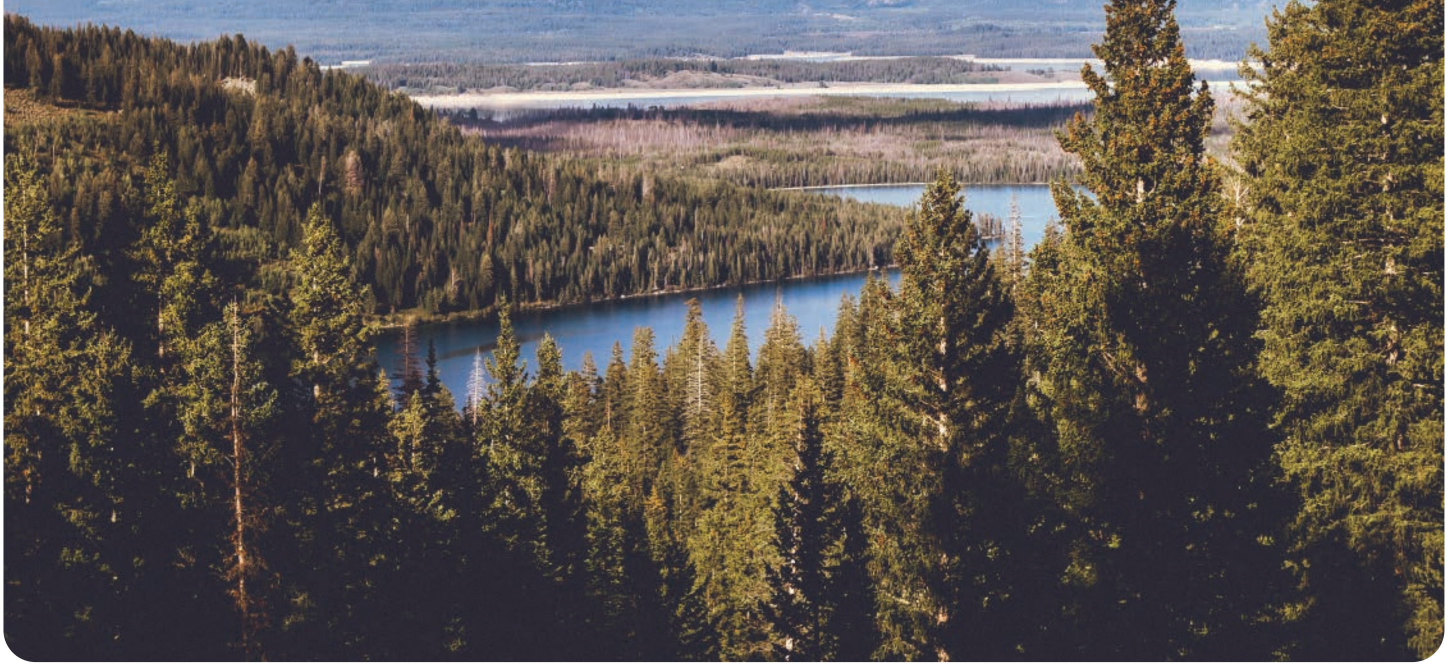
[14] Data collected from (International Atomic Energy Agency, 2022c).

[15] Micro-reactor is defined as a fission device capable of supplying between 1 Megawatt thermal (MWth) and 20 MWth.

[16] The International Atomic Energy Agency (IAEA) defines 'small' as under 350 Mwe (World Nuclear Association, 2023).



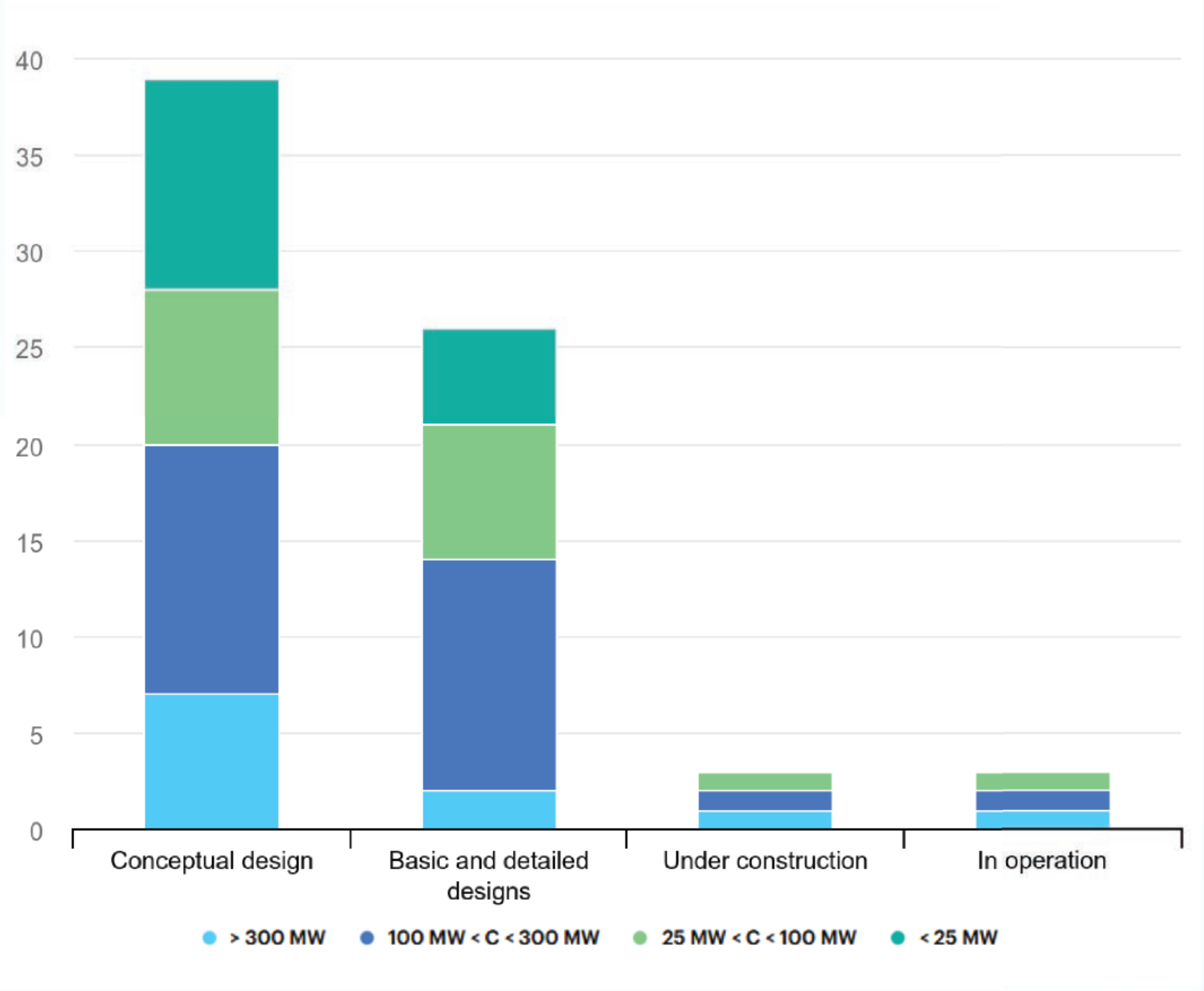
The current and proposed SMRs are powered by nuclear fission and capable of providing between 1 MWe and 300 MWe, equivalent per module (Nuclear Regulatory Commission, 2023c). Some SMRs are specifically designed to provide industrial process heat rather than electricity generation. A typical SMR has a five-year construction time, which compares favorably to the 12-year average construction time for large light water reactor (LWR) (The Australian Atomic Energy Commission, 2020).

The NRC treats SMRs as advanced reactors requiring licensing under either Part 50 (Nuclear Regulatory Commission, 2023d, p. 50) or Part 52 (Nuclear Regulatory Commission, 2024). However, in 2020, the NRC proposed rulemaking to address advanced non-LWR designs (Nuclear Regulatory Commission, 2023b). The proposed rule would streamline the licensing process and take advantage of passive accident mitigation features included with most new SMR designs.

Globally, about 65 SMRs are in either the design or planning stage. Three modern SMRs are operating in Russia, China, and India. The project phase and size of these SMR's are summarized in Figure 2.

Most SMR projects are in the conceptual and decision phases. If these projects materialize, there will be a significant shift in the demand for nuclear components. Contracts to develop parts for large nuclear power plants provide a steady income for manufacturers over the contract term, but new builds occur sporadically. These SMR designs provide a more constant source of income for manufacturers in between major projects.

Figure 2:
SMR Global Status (International Atomic Energy Agency, 2022b)



2.2 NUCLEAR MANUFACTURING SUPPLY FACTORS

Given the breadth of components needed to build a nuclear power plant, a range of firms produce the parts. One way to classify the nuclear components manufacturing firms is by the markets they serve as some companies focus solely on nuclear components while others serve multiple markets.

One specialized firm is Babcock and Wilcox Nuclear Technologies (BWXT), which contracted with TerraPower to design some of the unique nuclear components for the Kemmerer power plant (BWX Technologies, 2023). BWXT and similar firms carve out a niche by specializing in components associated with advanced nuclear designs. This expertise provides a market advantage where nuclear experience helps keep projects on time and under budget.

Other firms are generalized, producing nuclear components alongside components for other industries. Of the small components manufacturers reviewed, many served other markets applying manufacturing equipment and skills for easy entrance into the nuclear market (see Section 3.2). Manufacturing facilities producing components for aerospace, upstream oil production, and chemical facilities have experience developing similar types of parts used in the nuclear industry and with similar machinery. This creates a supply-side substitution effect where manufacturing facilities can produce parts for either the nuclear industry or other uses. Both the nuclear and general industrial markets have been served by these manufacturers. This makes these firms less sensitive to changes in the nuclear market compared to those that specialize in nuclear components.

Because many of the companies that supply nuclear components serve multiple markets, the trends in Wyoming manufacturing affect the State's capacity to uptake nuclear manufacturing. L&H Industrial is a recent example as their production experience in the oil field and coal industry provided a platform to adopt nuclear component manufacturing (Hurst, 2014). Existing manufacturing in relevant sectors makes transitioning into nuclear manufacturing easier.

Figure 3:
Wyoming and U.S. Manufacturing Employment[17]

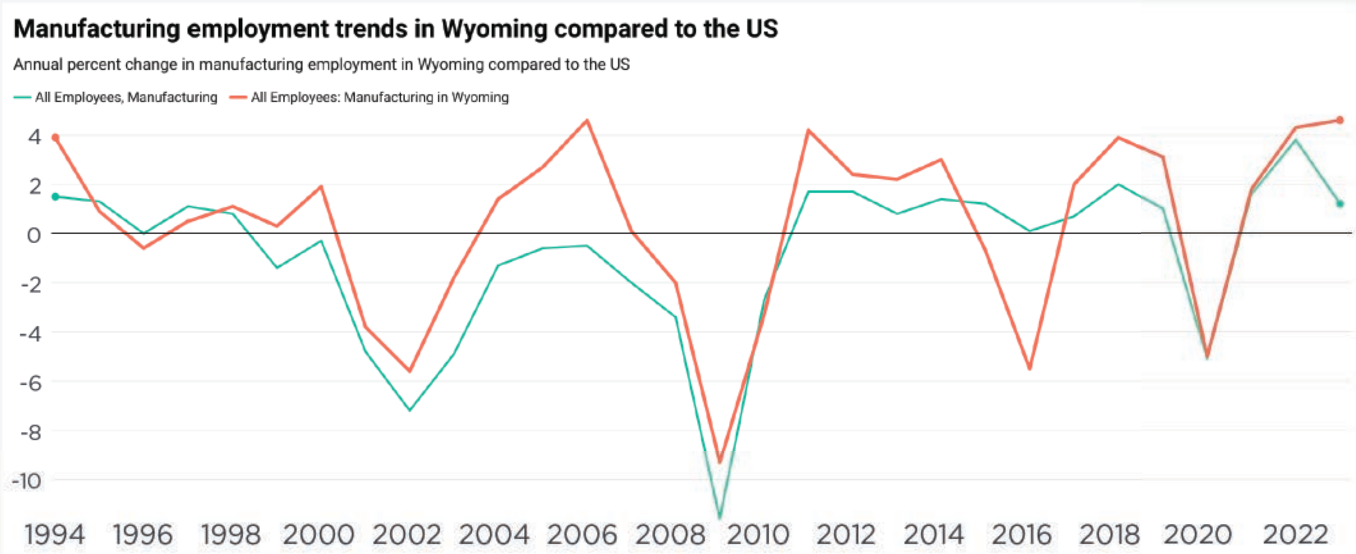


Figure 3 demonstrates that Wyoming manufacturing employment trends are consistent with the rest of the country. While there exist annual deviations, the State closely tracks the U.S. yearly change. This is evidence that Wyoming manufacturing rates (and nuclear component manufacturing) are driven by national and macro-economic effects.

One important manufacturing trend relevant to the State is the reduction in forge capacity. The U.S. lost heavy forging capability around 2000. For example, a 15,000-ton press, capable of handling 350-ton ingots, was required for several AP1000 reactor components. Four of the most complex parts of a nuclear power plant, the containment vessel, the reactor vessel, the turbine rotors, and steam generators, were commonly made from greater than 4,000-ton steel forgings, and almost none of these components are currently manufactured in the U.S. As shown in Table 3, heavy forging capability is currently available in Japan, China, France, South Korea, and Russia. Additional capability is being developed in Japan, South Korea, Czech Republic, and Russia. No new facility of this scale is currently planned for North America.

[17] Data sources used to create Figure 3 come from (U.S. Bureau of Labor Statistics, 2023a, 2024)

Table 3:
Heavy Manufacturing of Power (World Nuclear Association, 2021)

Country or Region	Company	Heavy Forging Press (tonnes)	Max, Ingot (tonnes)	RPV* sets/year
Japan	Japan Steel works	14,000 x 2	650	12
	JCFC	13,000	500	
	MHI	Nil, uses forgings to make RPVs		
South Korea	Doosan	13,000, 17,000	540	5?
China	CFHI	12,500, 15,000	715	5
	Shanghai (SEC)	12,500, 16,500	600	6
	China Erzhong	12,700, 16,000	650	5
	Dongfang Electric (DEC)	large		
	Harbin Electric Co	8000		4
India	L&T	9000, 15,000?	300	
	BHEL	10,000		
	Bharat Forge	12,500, 16,000		
Europe	Framatome, Creusot Forge	11,300, 9,000	500	
	GIVA Forgiatura	6,000	150?	
	Sheffield	10,000	200?	
	Pilsen Steel	10,200, 12,000	250	
	Vitkovice	12,000	250	
	Saarschmiede	8670, 12,000	370	
	Societa della Fucine	12,600	530	
	OMZ Skoda JS			
	ENSA	Nil, uses forgings to make RPVs		
USA	Lehigh	10,000	270	
	N. American Forgemasters	10,000	170	
	ATI	15,000	175	
Russia	OMZ Izhora	12,000, 15,000	600	4+
	OMZ Spetsstal	major	420	
	ZiO-Podolsk			4
	AEM: Atommash	15,000		5+
	AEM: Petrozavodsk	major		
Ukraine	AEM: EMSS	major	420	
South Africa	DCD-Dorbyl	1,000		

ADVANTAGES AND BARRIERS IN WYOMING

A set of empirical and qualitative analyses are applied to contextualize the opportunities and challenges related to fostering new nuclear component manufacturing investment in Wyoming. A scoring system ranging from *severe obstacle* (red) to *major advantage* (green) is given to each category of development (see Gebben & Peck, 2023). At the beginning of each section, the *Scoring Criteria* subsection provides the score and rationale. For those seeking a more thorough explanation, a detailed discussion of the steps used to identify the score is provided in the *Analysis* sub-section.

Before addressing the individual scores, the data and qualitative methodology applied across multiple sections is explained. An econometric model is employed which estimates the magnitude that different factors have on nuclear components manufacturing. This model provides insights into each of the six categories scored in the proceeding sections. The findings are presented in Table 4 and paired with a general explanation of the results. A technical description of the model is provided in Appendix (D). The model predicts that corporate tax rates, manufacturing employment levels, and the amount of nuclear power produced in a state are all factors that explain where nuclear components are manufactured. These estimates can be compared to the current conditions in Wyoming to inform policy decisions.

The variable estimated in the model is the number of American Society of Mechanical Engineering (ASME) certifications that relate to manufacturing nuclear components. ASME provides a series of certificates to manufacturers indicating certain quality assurance standards have been met. A subset of these certifications are issued uniquely to nuclear components manufacturers. These N-stamp certifications are granted to suppliers of safety related nuclear components of pressure containing systems[18]. More details about ASME certification are provided in Section 3.6. In lieu of obtaining firm level manufacturing data, these certificates provide an indication of the number of unique sets of firms that are producing safety related nuclear components and the diversity of those products[19,20].

The model of choice is a Poisson regression, estimating the number of nuclear related ASME certificates a state acquires each year (Nelder, 1974). A Poisson distribution is most appropriate when the outcome (number of certificates) can only be a whole number with a narrow range. Three alternative models are presented, each with different explanatory powers. The first two models presented in Table 4 have more precise estimates, but model three includes more potential factors. The first two models control for all time invariant attributes at the state level, such as weather[21] and regultory frameworks. The state fixed effect control in model one and two alleviates the risk of omitted variable bias but makes observing time invariant factors impossible[22]. The control variables capture effects of corporate tax rates, weather, and energy production[23].

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18 Data set sources: 1) National Oceanic and Atmospheric Administration (NOAA), regional temperature data, and natural disasters statistics 2) Energy Information Administration (EIA), active electricity production capacity (nameplate capacity). 3) Federal Reserve of Saint Louis, macro-economic factors, including employment numbers and population trends. Each source of data was combined and aggregated to the state level. This process is explained in Appendix (A).

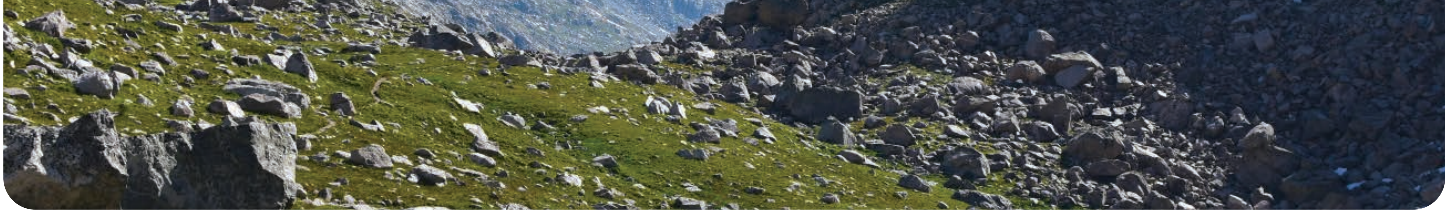
19 More information about the model assumption and results can be found in Appendix (C) and Appendix (D).

20 The ASME certificate information is a novel dataset created for this report, and the data collection process is outlined in Appendix (A).

21 While weather changes from year-to-year weather effects are fixed over time. Economic decisions made about firm location can only account for the expected long run weather effects. These effects are constant because deviations from the average weather conditions are definitionally unknowable. Weather variables are included only in model 3 of Table 4 because this model excludes the state fixed effect control. Therefore, weather is no longer colinear with other variables and acts as an important control.

22 See Appendix (E) for a more detailed explanation of the model differences.

23 These certificates are centered on the pressure system of the nuclear power plant. This can create selection bias when applied to other parts such as electrical systems. However, it is found that the existence of ASME certificates in a state is highly correlated with the existence of missing data. This suggest that the missing companies behave similarly to the available companies in the ASME certification data set. All companies that supplied parts for the AP1000 design, were collected for this comparison. See Appendix (K) for a discussion of possible selection bias.



The outcomes of the resulting three models are shown in Table 4. The first number reported in each row is the coefficient estimate of interest. These numbers should be interpreted as a percentage change in the number of certificates when the respective variable is increased by 1%[24]. The significance code next to the coefficient labeled with (*) indicates that the results are unlikely to be replicated by random chance.

The model estimates that a 1% increase in corporate tax payments reduces the number of certified nuclear component manufacturers in a state by between 0.27% and 0.31%. Another outcome of note is that states that have nuclear power plants are more likely to have nuclear component manufacturers. This effect scales with size, so that larger power plants have a more significant effect on manufacturing. All else equal, a state with 1% more nuclear production capacity is estimated to have 0.08% more nuclear component manufactures. See Section 3.5 for more details.

Intuitively, states with higher levels of manufacturing employment produce more nuclear components. A 1% increase in manufacturing employment is estimated to increase nuclear manufacturing by 0.78%[25]. This result suggests that the factors which promote manufacturing generally, such as State infrastructure, are just as important for establishing nuclear component manufacturing.

Another outcome is that firms are less likely to be in states that experience large natural disasters. For every 1% increase in the number of deaths caused by natural disasters including, but not restricted to, floods, hurricanes, and tornadoes, there is a 0.5% decrease in the number of certificates.

These results speak to multiple factors relevant to Wyoming, such as policy, location, economic, and existing industry factors. In determining the advantages and challenges of developing nuclear manufacturing in Wyoming, these coefficients will be applied given current circumstances in the State.

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[24] For example, the first coefficient in model one is -0.273. This implies that if a state increases the amount of taxes collected from corporations by 1%, that there will be a decrease in the number of operating nuclear component manufactures by -0.273%. From this a 10% increase in taxes would causes a -2.73% decrease. The first coefficient of -0.273 has two significance codes, indicating that under the model assumptions, there is less than a 5% chance that this coefficient could be found by random chance.

[25] In the state fixed effect model the coefficient for manufacturing employment is larger than the year fixed effect model, but it is no longer statistically significant. However, there is evidence that the effect is non-random. The standard cutoff of significance used is a 0.10 P-value, the heteroskedasticity cluster robust errors of the manufacturing employment have a P-value of 0.11, just over this threshold.

Table 4:
Poisson Model of Nuclear ASME Certificates (Ibid supra 18)

Dependent Variables	Nuclear Certifications		
Model	(1)	(2)	(3)
Variables			
Corporate Tax	-0.273** (0.119)	-0.312*** (0.119)	-0.287*** (0.089)
Manufacturing Employment	1.47 (0.938)		0.781** (0.357)
Unemployment	0.059 (0.130)		-0.116 (0.112)
Population	4.64* (2.52)	5.71** (2.23)	0.336 (0.592)
Other Certificates	0.016 (0.022)	0.026 (0.024)	0.031 (0.021)
Nameplate Capacity (NPC)			0.298 (0.475)
Nuclear NPC			0.077** (0.035)
Natural Disaster Deaths			-0.539 (0.338)
Avg HDD			-0.533 (0.579)
Avg CDD			-0.478 (0.679)
State Size			-0.220 (0.235)
Neighboring States NPC			✓
Fixed-effects			
Year	✓	✓	✓
State	✓	✓	
Has Corporate Tax			✓
Coastal			✓
Fit Statistics			
Observations	898	927	1,362
Squared Correlation	0.26856	0.26364	0.21528
Pseudo R^2	0.26901	0.26671	0.26447
BIC	1,430.5	1,452.0	1,470.4

Clustered (State & Year) standard-errors in parentheses | *Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*
All Continuous variables are logged
NPC: Name plate capacity
HDD: Heating degree days, are the average for a given state
CDD: Cooling degree days, are the average for a given state
State Size, is the natural log of square miles

3.1 ECONOMICS

Large Components — Major Obstacle

Small Components — Minor Obstacle

Economic Barriers: Scoring Criteria

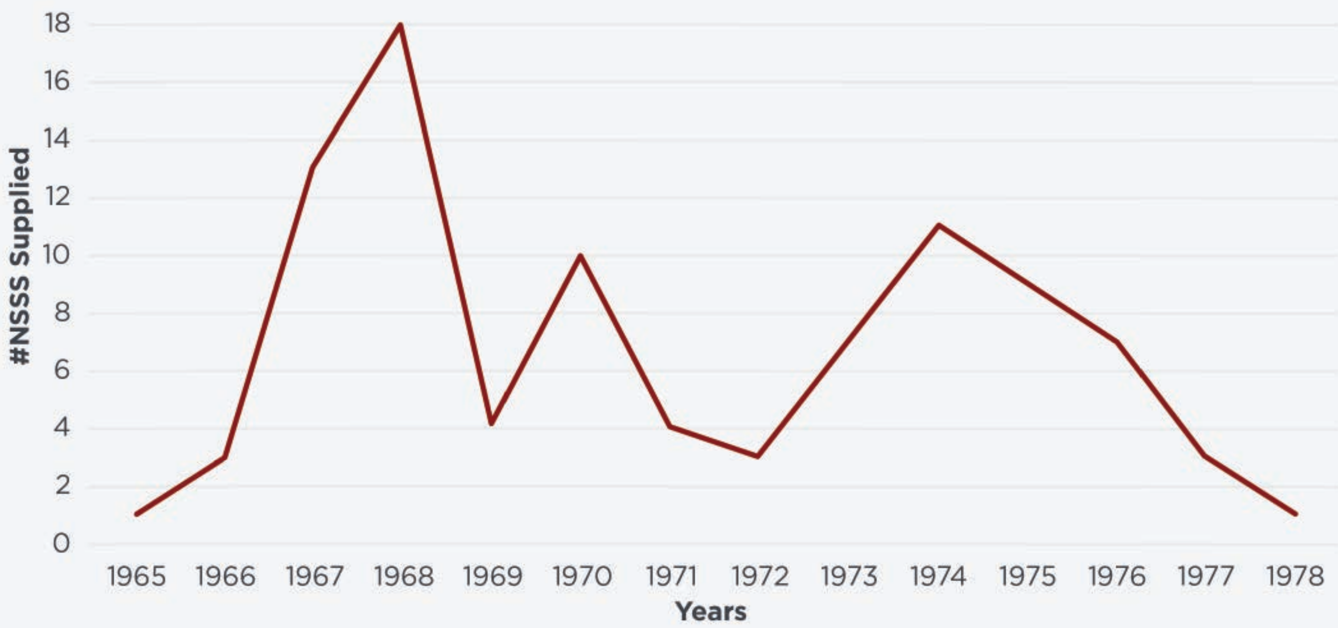
Declining U.S. manufacturing rates are found to be an obstacle for developing nuclear components in Wyoming. This is especially true for large and complex component production, which necessitates extensive infrastructure to be manufactured. The challenges of establishing large component manufacturing in Wyoming are exacerbated by declines in domestic demand for nuclear power plants. Nuclear reactors are usually produced in the same country where the power plant is installed. This dampens the ability of U.S. manufacturing firms to engage in international trade as nuclear power expands in Asia. However, production of small components used in nuclear power plants[26] is not currently constrained by existing forge capacity and these parts continue to be produced domestically[27]. Therefore, we identified the economic barriers for small components as a *minor obstacle* but a *major obstacle* for large components.

Economic Barriers: Analysis

During the early development of nuclear power, U.S. firms were the primary supplier of nuclear reactors. General Electric (GE) and Westinghouse (WH) were the two largest manufacturers. By the mid-1970's, U.S. manufacturing hit its peak with 75% of all nuclear reactors purchased coming from a U.S. firm (Lévêque, 2014). In recent years, the largest Generation III reactors have been produced entirely internationally due to the loss of U.S. capacity in the early 2000's[28]. Figure 4 provides a timeline of the number of U.S. produced nuclear stem supply systems (NSSS), which constitutes the main large components.

[26] Including SMR designs.
[27] Under future growth paths, foraging capacity may become an obstacle for small components. For the current scoring criteria, this is not considered a constraint.
[28] See Table 3 for global large forge capacity.

Figure 4:
Reactors Supplied by U.S. Firms[29]



Trade theory provides insights into these manufacturing trends, as every country possesses a comparative advantage in the production of a good. Gross Domestic Product (GDP) is maximized when a country specializes in manufacturing specific products and trades the surplus to other countries (Ricardo, 1819; Smith, 1776). For this reason, there is a tendency for geographic clustering of industries, with a single country providing a large share of any given market. U.S. manufacturing employment had an upward trend from 1945 until reaching an apex in 1979 at 19,953 employees. Since that period, total manufacturing employment has declined by 34% (U.S. Bureau of Labor Statistics, 2023a). This suggests the 1960's and the early 1970's was a period where the U.S. had a comparative advantage in manufacturing. Combined with the U.S. technological advantages in the nuclear industry, there was a strong incentive to produce nuclear components in the U.S. instead of overseas. The decline in manufacturing employment during the late 1970's is evidence of the loss of U.S. comparative advantage[30] in manufacturing. Alongside the development of nuclear technologies in other nations, the economic drivers promoting U.S. reactor production were diminished.

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[29] Data compiled from IAEA (International Atomic Energy Agency, 2022c). Each entry point is the number of NSSS, which includes reactors, associated with a power plant that began construction in the given year.

[30] Comparative advantage is determined by the productivity ratios of goods, not the absolute output. There are gains to trade even when a country is more efficient at producing every good independently. Therefore, the U.S. may lose the comparative advantage in nuclear components manufacturing as other industry outputs change, even if net productivity of components does not decrease.

The nuclear industry has changed since this period of peak U.S. production, while average reactor output has increased, taking advantage of economies of scale (Ramana, 2021). The increasing reactor output has improved cost competitiveness of developing countries with rising electrification rates, such as China (Kinsey et al., 2018). As other countries developed new manufacturing facilities under these conditions, the domestic manufacturing fleet has stagnated and the current average age of operating U.S nuclear power plants is 42 years (Energy Information Administration, 2023e). Existing U.S. infrastructure is incapable of producing the largest modern reactors, which require presses with a capacity of more than 350 tons[31] (Kinsey et al., 2018). This barrier can be addressed through technological innovation that makes smaller reactors cost competitive or technology that allows large components to be manufactured modularly (see Section 3.4).

Another factor leading to this shift was a reduction in national demand for nuclear components. If the nuclear components industry had full competitive trade and a global market, the expectation is that one or two countries will provide most of the world's nuclear output. However, the source of supply for nuclear components, and the source of demand from nuclear power plants, are intertwined at a national level. Figure 5 provides a spatial linkage analysis between the companies producing nuclear reactors and the end location of those reactors (Markard et al., 2020). The bubbles in this chart represent a country's node of influence. The largest central bubble includes all firms in the U.S. Firms like GE and WH have supplied reactors to countries such as France, China, and Japan, but only indirectly through collaboration with existing local companies. Nearly all power plants are supplied by a firm in their own region, and these regional clusters are highly insular.

Some countries, such as Russia, have government owned industries, with associated subsidies explaining the lack of trade flow. Transportation costs also contribute to this local clustering. It is cheaper to construct large, specialized equipment, such as mining haul trucks, on site due to the complexities of transport. Similarly, the larger the nuclear component, the more cost effective it becomes to manufacture it near the nuclear power plant site.

[31] Current global forge capacity is shown in Table 3.

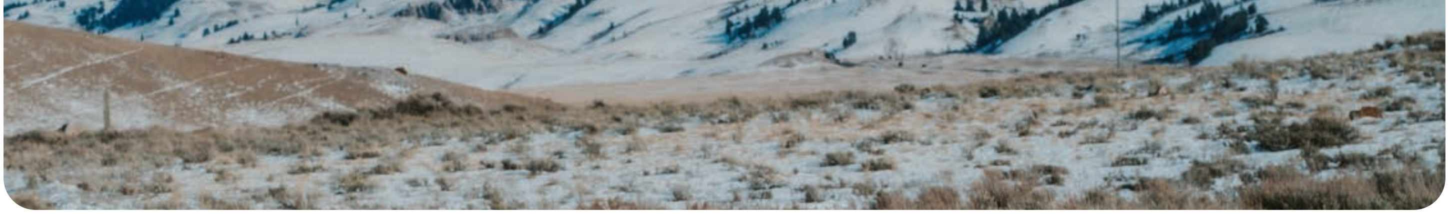
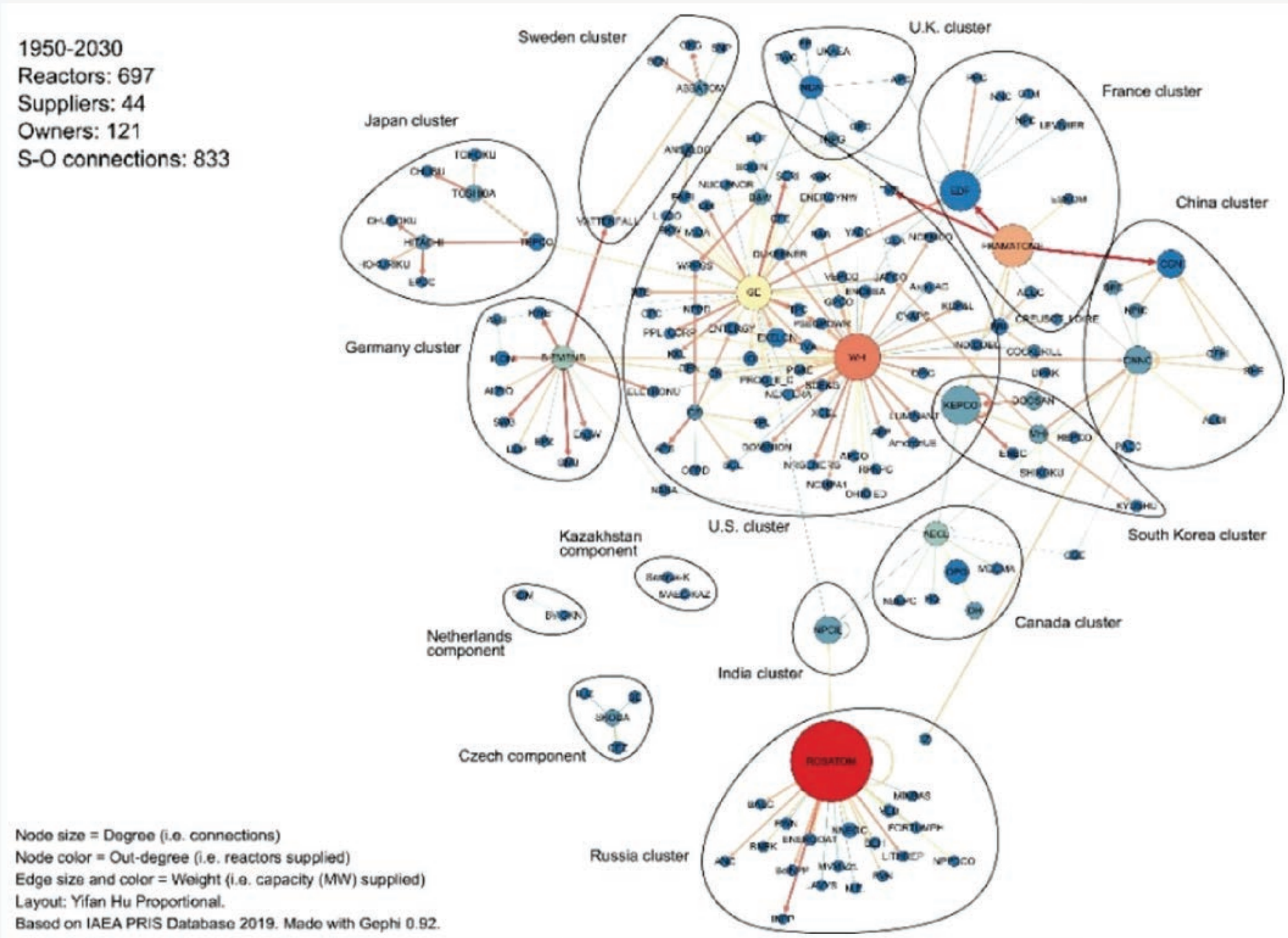


Figure 5:
Historic Location Cluster Analysis (Markard et al., 2020)



Since the market for reactors is segmented nationally, demand for nuclear components in the U.S. has a more significant effect on the domestic supply chain than international demand. Only two new nuclear units have become operational in the U.S. over the last decade, with capacity additions peaking in the early 1990's. Figure 6 shows the evolution of this local network presented in Figure 5, with the U.S. region declining in the quantity of nuclear reactors supplied and demanded starting in the 1990's.

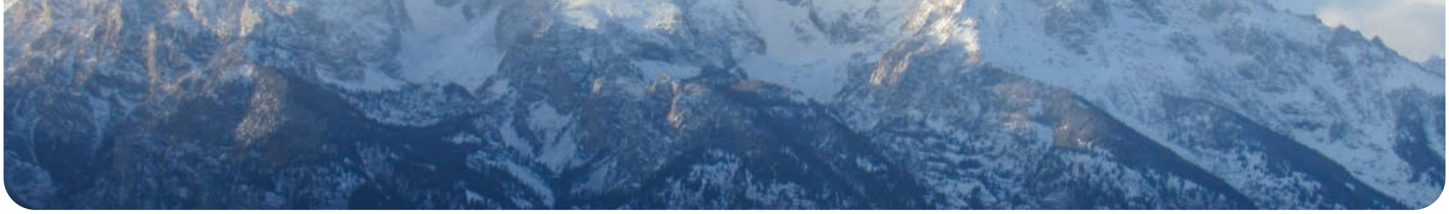
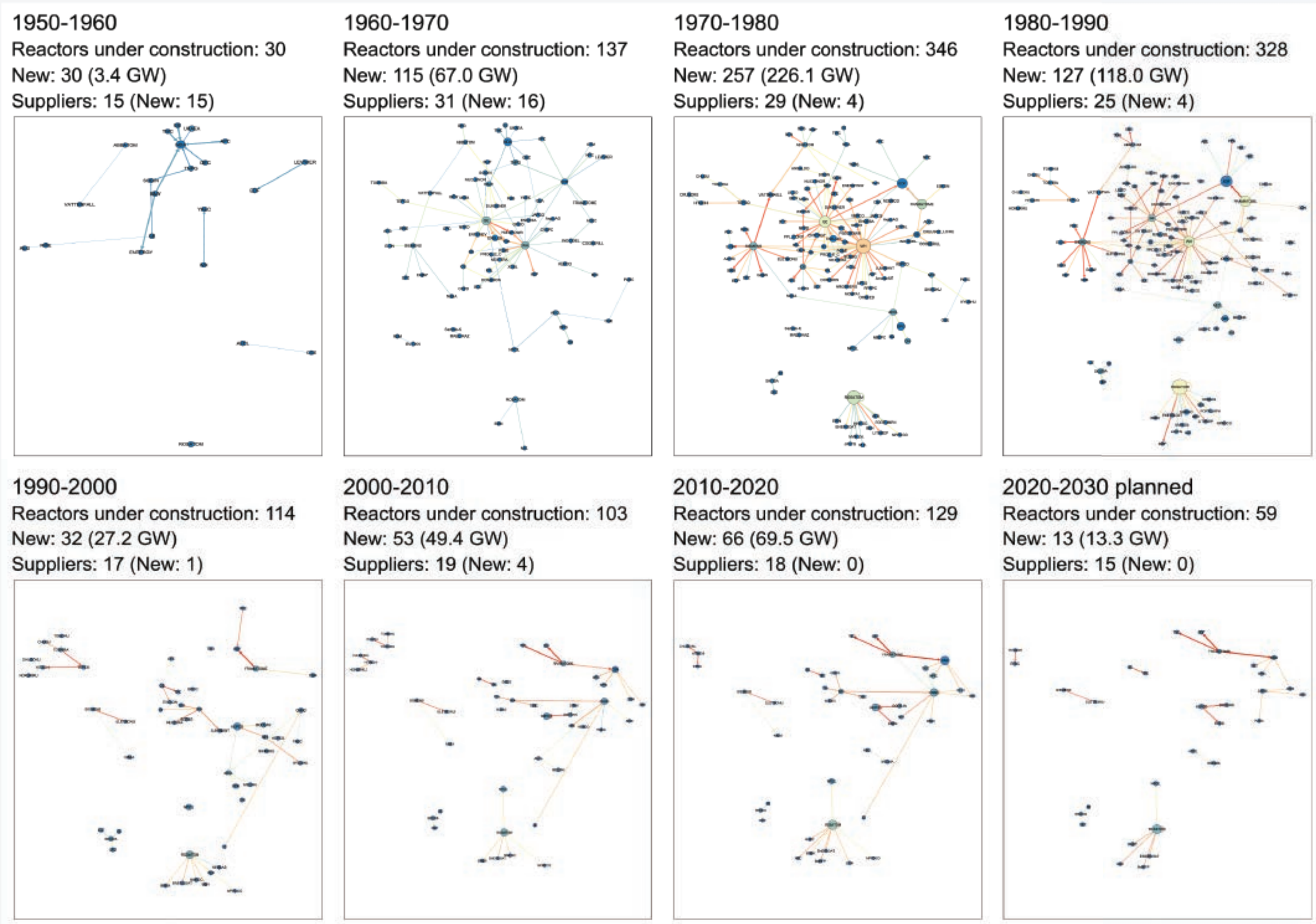
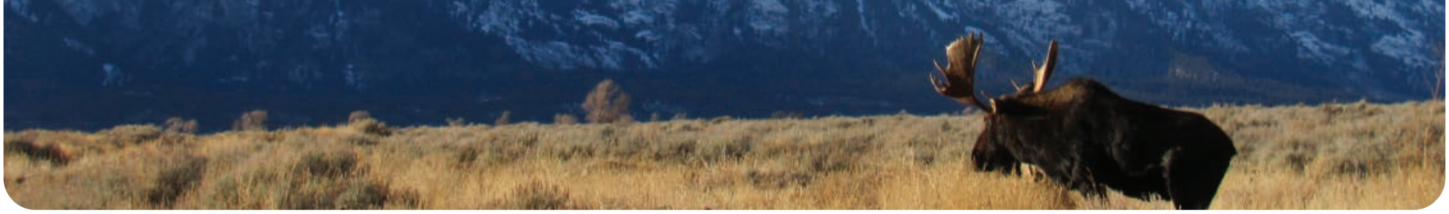


Figure 6:
Reactor Component Network Over Time (Markard et al. 2020)

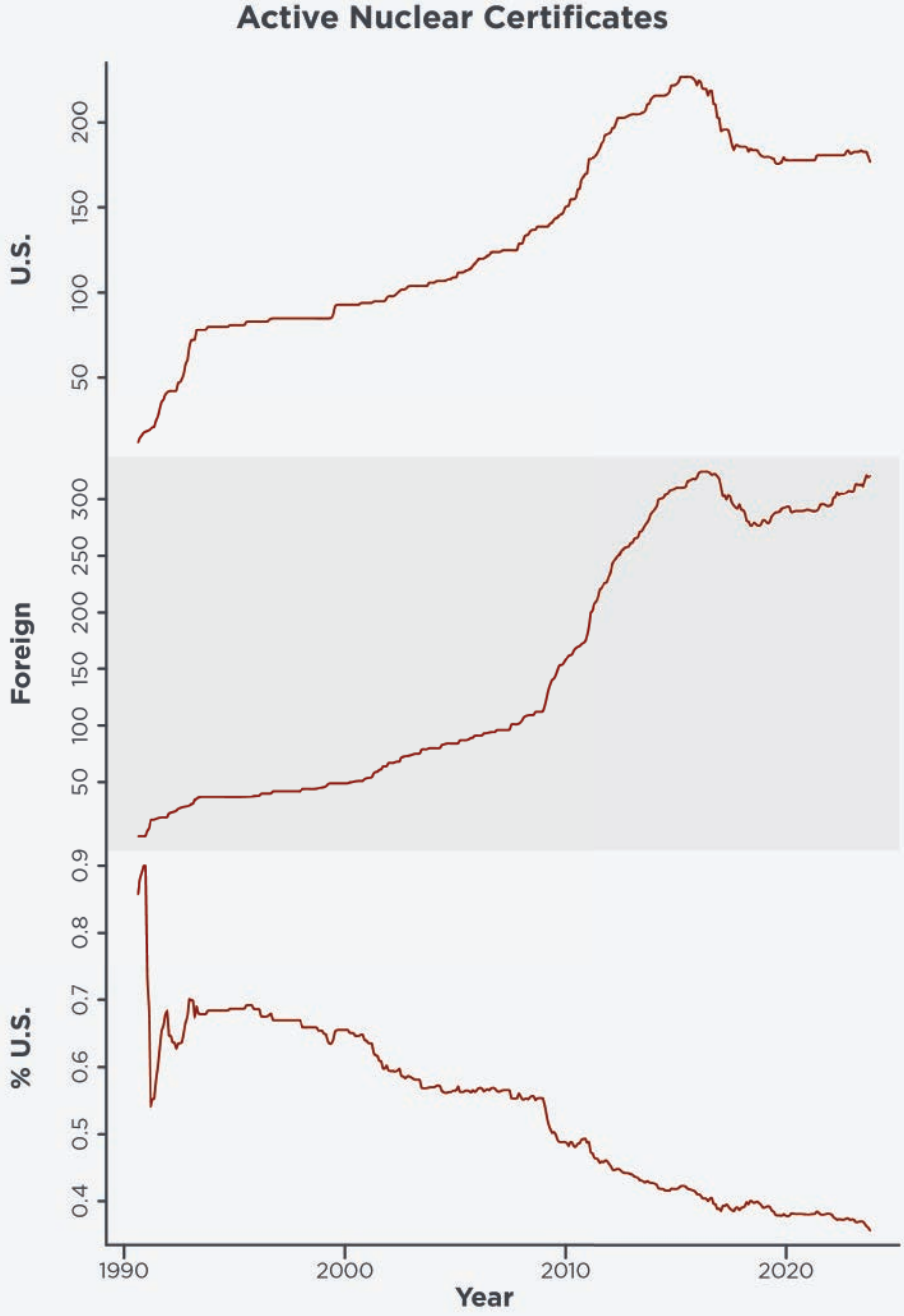


At first glance, it seems possible that historic nuclear manufacturing in the U.S. would allow reactors produced domestically to be exported. However, the supply from U.S. firms and the demand within the country are highly connected. From the 1970's to the 1990's both the U.S. supply of reactors and U.S. demand of power plants constitute the largest nuclear node in the world. From the 1990's to the present the nodes of production are clustered in countries with nationalized nuclear industries. The remaining flow of trade comes from patents, with U.S. firms selling designs rather than physical material (Lévêque, 2014).



The manufacturing of small nuclear components has different economic challenges than reactors, and are currently produced in the U.S. As an indicator of the rate of small component production, the number of active ASME nuclear certificates is plotted in Figure 7. While ASME certificates do not encompass all nuclear components, evidence in Appendix (K) suggests the trends in ASME certificates are applicable to the entire small nuclear component market. The number of companies maintaining these certificates informs the global small component manufacturing trends, and the state of U.S. production.

Figure 7:
Component Manufacturing Time Trend (Ibid supra 20)



The number of ASME nuclear certificates increased from 1990 until the mid-2010's, a period when U.S. reactor production was dormant. The shared trend between certification rates in the U.S. and foreign firms suggests the main economic drivers of small component manufacturing are global in nature. Compared to large reactor production, small components are a more competitive market as small components require less upfront investment, are frequently co-produced with components for other industries, and are easier to transport. Also, power plant owners are more likely to maintain monopsony[32] control over reactor production than small components. Taken together, these factors explain why the small-scale nuclear components are driven by global demand shocks, whereas large reactors respond almost entirely to national demand.

Global shocks to nuclear power demand and supply explains most of the certification changes for U.S. and foreign production. To formally test this linkage, a vector error correction model (VECM) is presented in Appendix (F). This model tests for long term convergence of U.S. production, foreign production, and uranium prices. The results confirm that there is a long-running dynamic between the U.S. and foreign certification levels. After three years, approximately 80% of the U.S. nuclear certification levels can be explained with global and regional shocks to certification levels[33]. There has been a steady decline in the ratio of U.S. to foreign certificates. Shortly after data became available, U.S. firms accounted for 70% of all ASME nuclear certification, dropping to below 40% by 2023. The number of active certificates in the U.S. began to decline in absolute terms starting in 2019.

Summary

Under these economic constraints, constructing large nuclear components in the U.S. is challenging. Without a new source of domestic demand for traditional LWR nuclear power plants, the national reactor manufacturing industry will not reemerge. For the economic score to improve, one of two restrictions need to change. Either domestic demand needs to increase or the global trade network needs to become more open. Comparatively, small components are a more competitive market and there remains active U.S. production. Over time, the ratio of U.S. to foreign firms producing small components has declined, yet a sizable portion of these components continue to be produced domestically. These factors lead to a score of *minor obstacles* for small component manufacturing, but a *major obstacle* for large component manufacturing in Wyoming.

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[32] Monopsony is the opposite of a monopoly, where there is one buyer rather than one seller. In this case the large components are only purchased by the few firms constructing nuclear power plants. The vertical integration of some power markets has led to monopsony power in the electricity market (Wilson et al., 2020).

[33] Uranium prices are included to capture demand shocks that are not present in the response of manufacturing firms but are found to play a minor role in certification rate formation.

3.2 EXISTING INDUSTRY

Large Components
Major Obstacle

Small Components
Moderate Advantage

Existing Industry: Scoring Criteria

Existing industries are found to promote the growth of small nuclear components manufacturing in Wyoming but are determined to be a *major obstacle* to large component manufacturing.

The location of small component manufacturing firms is evaluated using econometric and statistical models. Wyoming has the highest rate of manufacturing GDP per capita in the country, which is an advantage for the establishment of nuclear small component manufacturing in the future. Manufacturing firms that add nuclear small component lines are found to be larger well-established companies. These older firms tend to focus expansion efforts in the nuclear sector which diversifies their market reach. The non-nuclear industries served by these companies are often present in Wyoming, such as energy production, oil and gas, and aerospace. For this reason, the extant manufacturing sector in Wyoming provides a *moderate advantage* to locating in the State.

The lack of exceptionally large manufacturing capacity in the U.S. is a *major obstacle* to fostering a nuclear manufacturing sector for the largest nuclear components in the State. Without significant financial investment, these large components will be produced in other nations. This score can be viewed on a spectrum with moderately large components falling in between the two scores.

Existing Industry: Analysis

Whether existing industries generate an economic incentive or economic barrier for Wyoming depends on the attributes of the nuclear manufacturing sector. The characteristics of nuclear component firms are explored through empirical analysis. The models predict N-stamp certification rate. Due to the ability to adjust manufacturing capital over the long term, the rate of certification from ASME N-stamps is applied more broadly to the entire small components market[34]. The data set also includes ASME certification records for non-nuclear applications, which is used to compare nuclear and non-nuclear firm behavior. The results suggest the industry composition promotes an expansion of nuclear component manufacturing in Wyoming.

[34] See Appendix (C) and Appendix (K) for further justification of this assumption.

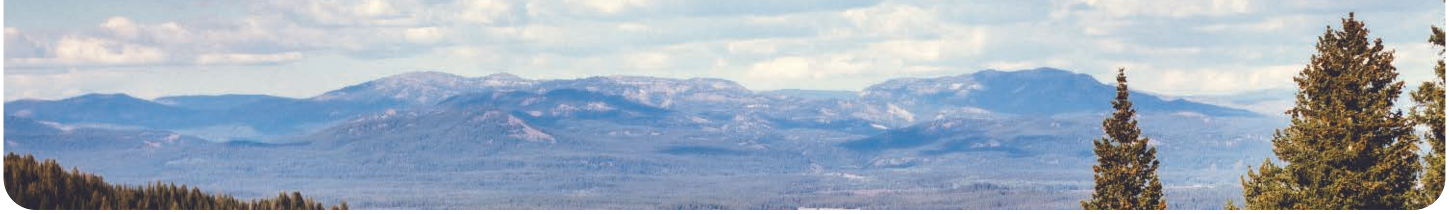
Response of Manufacturing Firms when Entering the Nuclear Market

Firm characteristics were evaluated, including the firm size, age, type of products manufactured, and expansion path. Since U.S. companies are primarily involved in small component manufacturing, the remainder of this section refers to small nuclear components when discussing firm structure, unless otherwise specified. Large components are scored as facing a major obstacle based on the forge capacity limitations explained in Section 2.2 Table 3.

The response of the manufacturing companies after entering the nuclear market was investigated using econometric models. Different industries have varying levels of flexibility in location and in production. In the case at hand, nuclear components can be created by: 1) adding a new nuclear component manufacturing facility; 2) expanding production capacity at existing facilities; or 3) converting existing manufacturing lines into nuclear components manufacturing. Each of these options is likely to be at play at the margins.

When there is an increase in the price of nuclear components, existing firms face two changes in incentives. Most directly, the value of nuclear components has increased so the optimal production level is elevated. This causes an expansion in output. More subtly, the profit ratio of non-nuclear components to nuclear components decreases, all else equal. This leads to a substitution from non-nuclear production to nuclear production, decreasing non-nuclear output. For Wyoming to develop a component manufacturing industry, these elasticities need to be identified. Further, the ability to acquire new manufacturing in the State depends on whether the expansion into nuclear is focused on existing firms or startups adding new capacity.

These responses can be evaluated using the ASME certification data. If firms enter the nuclear components market by switching current production, then it is expected that existing non-nuclear ASME certificates will be allowed to expire, and all new certificates will be in the nuclear category. If companies employ a strategy of adding new nuclear production capacity without switching production, then it is expected that all existing non-nuclear certificates will be maintained, but most new certificates will be for nuclear components. Finally, if firms employ a mix of strategies, then a hybrid of these two responses will result where some non-nuclear certificates will be allowed to expire and future ASME certificates will contain a mix of nuclear and non-nuclear certificates. The nuclear to non-nuclear ratio of the existing and new certificates is expected to converge over time.



To answer this question, a difference in difference (DiD) procedure was used. This methodology is quasi-experimental, leveraging sudden policy changes to delineate causality. In this case, the effect of a company applying for a nuclear ASME certificate on the level and mix of product lines is estimated. Data is aggregated to the company level. The average number of ASME certificates per year is calculated for each firm pre and post the development of a nuclear components line. If companies expand on the extensive margin, then the total number of certificates will increase after nuclear components are added[35]. If the firm substitutes one production line for another, then the number of non-nuclear certificates will decrease as nuclear manufacturing is developed.

Figure 8 and Figure 9 plot the average number of new certificates applied for by companies that eventually adopt nuclear component manufacturing, corroborating the regression results. Figure 8 plots the total number of certificates applied for (inclusive of nuclear certificates) while Figure 9 plots only the non-nuclear certificates[36]. The lines in each figure represent a locally estimated scatterplot smoothing regression, with the grey region representing the 90% confidence interval. The black solid line represents the average number of ASME certificates applied for by companies before they are issued a nuclear type certificate. The red line presents the same data, but only after the companies have been issued their first nuclear certificate[37]. Both lines compare the same set of companies, but at different periods of time. Figure 8 shows little deviation between the two series. The red line is higher than the black line suggesting the adoption of nuclear component manufacturing results in more ASME certificates being acquired.

Figure 9 is more striking as there is a clear and continuous gap between the number of certificates acquired for all non-nuclear related fields once a company begins nuclear parts manufacturing. This suggests that companies change focus once they adopt nuclear component manufacturing. While there may be an increase in the number of ASME certificates, the larger effect of adopting nuclear manufacturing is a diversion of resources into developing the new nuclear product lines.

[35] This estimate is sensitive to assumptions about overall output ratios, to license numbers. However, the results hold, if increasing licenses is assumed lead to the production of more products.

[36] Such as a pressure vessel certificate, which is used as a quality assurance when applied to other industries like oil and gas development.

[37] Such as a N-stamp.

Figure 8:
Overall ASME Certificate after Adopting Nuclear Components (Ibid supra 19)

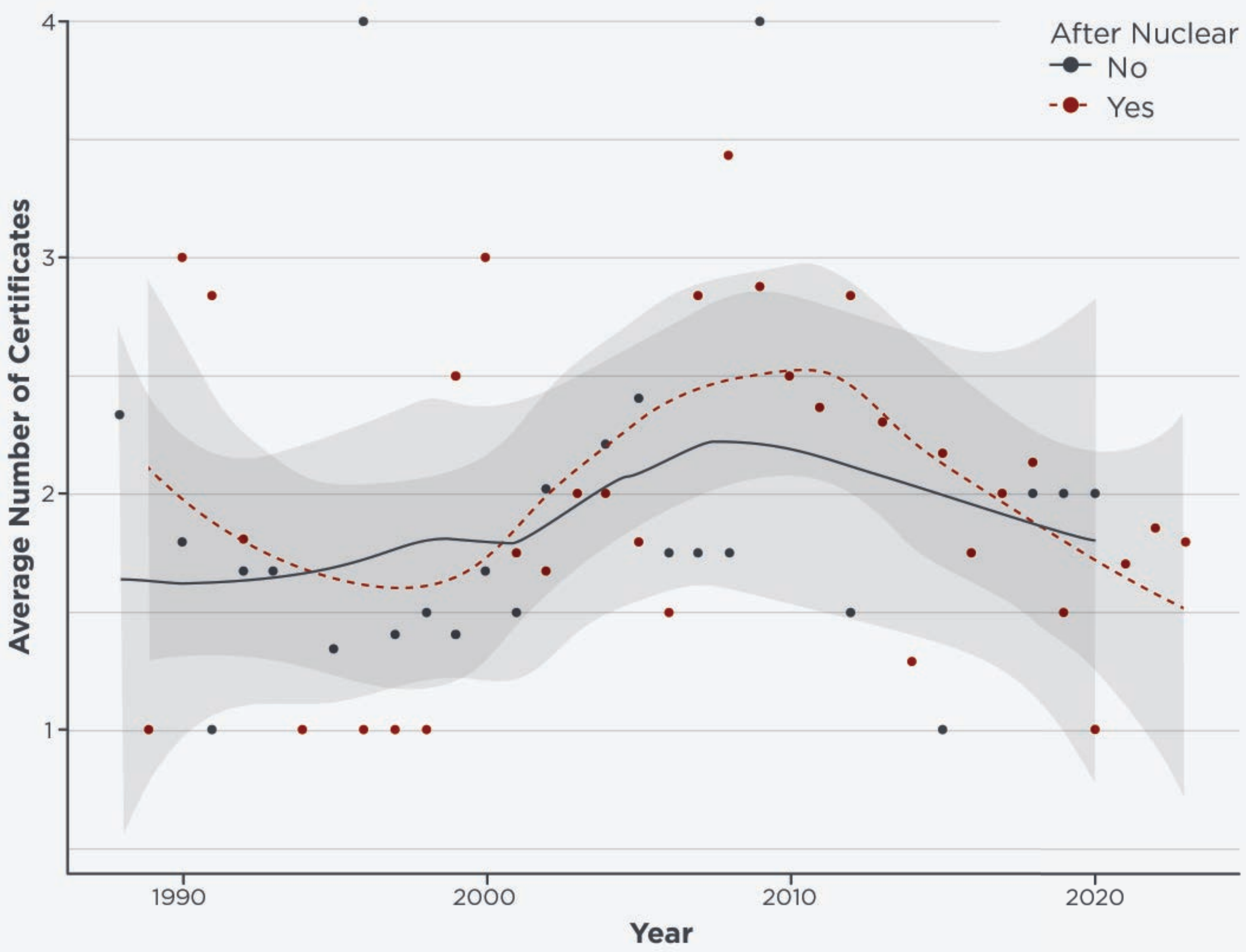
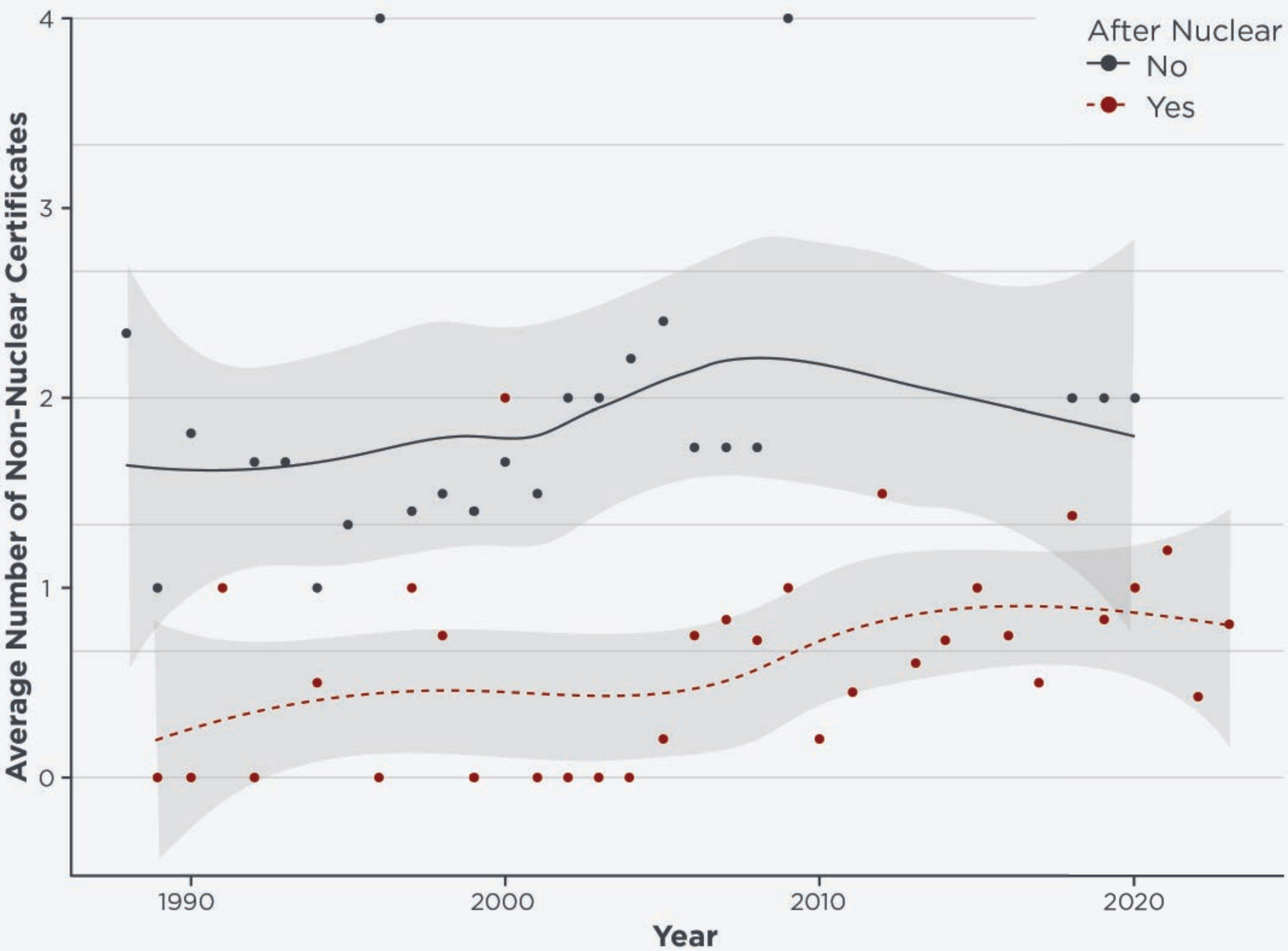


Figure 9:
Non-Nuclear ASME Certificates after Adopting Nuclear Components (Ibid supra 19)



The results of the DiD model can be seen in Table 5. Analysis is completed at both the firm level and facility level. The company level model is preferred because the dataset is larger[38]. The regression method accounts for more unobservable variables than in Figure 8 and Figure 9 and provides a direct estimate of the effects magnitude, but the results of the two methods are in concordance.

[38] The facility level analysis is provided as a robustness measure of the company results.

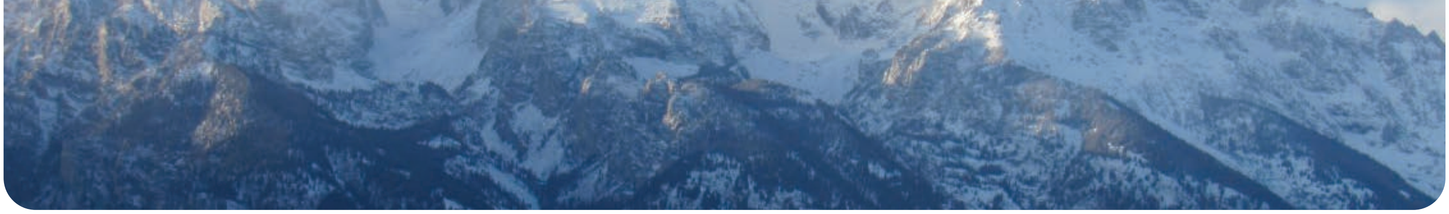


Table 5:
Difference in Difference Model of Nuclear Component Adoption (Ibid supra 19)

Dependent Variable:	Number of ASME Certificates			
	Company Level		Facility Level	
	Non-Nuclear	All	Non-Nuclear	All
Model:	(1)	(2)	(3)	(4)
Variables				
Post	-2.289***	0.2915**	-16.17***	0.8471*
	(0.3883)	(0.1360)	(1.856)	(0.4516)
Fixed-effects				
Company	✓	✓		
Year	✓	✓	✓	✓
Country	✓	✓		
Facility			✓	✓
Fit statistics				
Observations	304	304	61	73
Squared Correlation	0.62525	0.54996	0.99423	0.97374
Pseudo R^2	0.26016	0.11273	0.38736	0.21760
BIC	1,475.5	1,679.9	349.16	461.46

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

The results from Table 5 indicate that when manufacturing firms decide to adopt a nuclear component line, they continue to focus development in the nuclear sector to the exclusion of other types of certificates. The median company that applies for a nuclear components certificate reduces the number of ASME certificates not associated with the nuclear industry by 90%[39]. However, the overall number of certificates increased by 33.8%[40]. Both results are unlikely to be reproduced by chance under the model assumptions[41, 42].

39 This percentage is calculated by raising "e" to the coefficient estimated (-2.289). $-0.9=e^{-2.289}-1$.

40 $0.338=e^{0.2915}-1$.

41 They are statistically significant, at a 5% level.

42 Fixed effects (FE) of countries, controls for time invariant polices, FE of companies remove the median effect of the companies, and FE of Year remove macro trends at the yearly level.

The result of this regression only predicts future investments choices and does not determine if the adoption of nuclear manufacturing reduces existing production of non-nuclear components. For this, statistics are provided about the certification maintenance of firms that enter the nuclear market.

Composition of ASME Certificates

Table 6 evaluates the differences in the non-nuclear certificates between firms that have entered the nuclear industry and those that have not[43]. These findings suggest that nuclear component companies have a comparable mix of non-nuclear certification before entering the nuclear industry. Importantly, nuclear manufacturing firms pay to maintain existing ASME certificates. Combined with the results in Table 5, this is evidence that companies do not convert existing product lines. It also suggests that there is a path to apply experience in manufacturing components for other sectors to the nuclear industry[44].

Table 6:
Nuclear Component Manufacturers Summary of Other Certification vs Total Sample (Ibid supra 20)

	Pressure Vessels		Boilers		Safety Valve	
	Nuclear	**Non-Nuclear**	**Nuclear**	**Non-Nuclear**	**Nuclear**	**Non-Nuclear**
Fraction of Total	63.50%	62.95%	21.41%	24.11%	7.30%	3.36%
Active Certificates	88.12%	81.13%	85.23%	78.56%	83.33%	90.34%
Avg Issuance Date	2007-02-12	2012-12-04	2005-10-14	2012-02-21	2009-06-29	2010-05-10
	Difference Between the Both Group and the Non-Nuclear Group					
Fraction of Total	0.55%		-2.70%		3.94%	
Active Certificates	6.99%		6.66%		-7.00%	

	PP: Pressure Piping		Parts Fabrication		Other	
	Nuclear	**Non-Nuclear**	**Nuclear**	**Non-Nuclear**	**Nuclear**	**Non-Nuclear**
Fraction of Total	6.08%	6.54%	0.73%	1.16%	0.97%	0.27%
Active Certificates	80.00%	74.48%	100.00%	97.39%	75.00%	90.36%
Avg Issuance Date	2008-04-17	2011-07-02	2019-12-16	2020-10-29	2007-04-17	2011-05-12
	Difference Between the Both Group and the Non-Nuclear Group					
Fraction of Total	-0.46%		-0.43%		0.70%	
Active Certificates	5.52%		2.61%		-15.36%	

43 The nuclear category is any nuclear firm that has acquired both nuclear and non-nuclear certificates, allowing for a comparison with firms outside of the nuclear industry.
44 This may be limited to pressure containing components since other components have missing data.

Of the nuclear manufactures that also own non-nuclear ASME certificates, 87% of the non-nuclear certificates remain active compared to 81% for companies that do not produce nuclear parts. The average issuance date of the company's first certificate is older for the nuclear industry. The two groups have a similar mix of ASME non-nuclear certificate types, but the nuclear industry produces more pressure vessels and safety valves. This makes sense, as these are two common parts required in a nuclear power plant.

Additional data was collected about these nuclear component firms to identify general patterns. A sample of 20 companies that that have acquired a ASME nuclear certificate was reviewed in depth[45], improving data richness. From this, it was found that 95% of all companies are involved in multiple industries, with the most common industries being oil and gas and power generation. No company was founded less than a decade prior to being issued an ASME certificate[46].

Combining these findings with the regression results provides further insight. Component manufacturers that begin to target the nuclear industry do so after establishing products in other industries. Indicating that this is an area of expansion for the firms. The regression results suggest that the rate of growth increases after a company enters the nuclear market. However, markedly fewer non-nuclear certificates are applied for once the company begins producing nuclear components. These companies do not allow old certifications to lapse and, on average, have higher maintenance rates of certificates in every ASME category other than "safety valves"[47] and the "other"[48]. Taken together, these results are indicative of companies that are diversifying as they grow rather than switching industries.

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45 These 20 firms were selected from the subset of companies that have no non-nuclear certificates. This will establish if the model is selecting for older firms. If these firms are startups or if they only produce nuclear components the model is invalid.

46 This alleviates the concern that the DiD suffers from selection bias by evaluating only firms with multiple product lines. The facilities that are issued nuclear related ASME certificates had prior non-nuclear component production, but they did not acquire an ASME certification for this production. This means the observations in the DiD that have both nuclear and non-nuclear certificates are comparable to the observations that are dropped. The model is not selecting for firms that are more diverse in production. Further evidence is provided in Appendix (G).

47 7% lower.

48 15% lower.

Firm Size and Maturity

The final analysis performed to identify the importance of existing firms, disentangles the effect of firm size and age on the nuclear industry. Start up and established firms have a distinct set of incentives that affect location choice and production flexibility. To determine the importance of the existing Wyoming manufacturing sector, an econometric model was used to predict the odds of a component manufacturing firm being in the nuclear sector.

The model selected was a logistic model (logit) with country fixed effects[49], used to predict whether a firm will have at least one nuclear related certificate. The variables used in the model are the overall number of certificates, the number of unique locations the company maintains, as well as the number of certificates under each ASME category[50]. The results are provided in Table 7.

Table 7:
Logit Model of Nuclear Component Firms (Ibid supra 19)

Dependent Variable:	Facility has a Nuclear Certficate	
Model:	(1)	(2)
Variables		
Number of Locations (ln)	4.029***	
	(0.3845)	
Number of Cert.	0.2536***	
	(0.0728)	
Number Terminated	0.1004	
	(0.0761)	
Date of First Cert.	-4.79×10^{-5}**	-5.21×10^{-5}***
	(2.14×10^{-5})	(9.07×10^{-6})
Pressure Vessels	-1.362***	0.1192
	(0.1716)	(0.1169)
Steel Plate Heating Boilers	0.0072	-0.1071
	(0.1067)	(0.1085)
Potable Water Heaters	-0.0851	0.1244*
	(0.0734)	(0.0749)
Power Boiler	-0.3524*	0.2038
	(0.1935)	(0.1402)
Miniature Pressure Vessel	0.1623	0.0997
	(0.1120)	(0.0830)
Pressure Piping	-0.1579	-0.0318
	(0.2005)	(0.1252)
Safety Valve	-0.6992**	0.1744
	(0.3373)	(0.3573)
Power Boiler Safety Valve	0.1174	0.0587
	(0.3395)	(0.4145)
Plastic Pressure Valves	-0.2876***	0.0975***
	(0.0395)	(0.0271)
Fixed-effects		
Country	Yes	Yes
Fit statistics		
Observations	7,791	7,791
Squared Correlation	0.66607	0.03772
Pseudo R^2	0.72250	0.12798
BIC	999.00	2,286.9

Clustered (Company) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

49 This fixed effect control government policy, weather and other effects that are constant across time.
50 That are not specifically related to the nuclear industry.

A key finding is that the more manufacturing buildings owned by a company, the more likely they are to enter the nuclear industry. While it is intuitive that a company with more certificates is more likely to have a nuclear certificate by random chance alone, this may not be the case. If small startup companies were the main developers of nuclear components, the outcome would be reversed. Large firms are always more likely to have a nuclear-related stamp if the distribution is random, but not if there is a selection for small firms.

Interestingly, there are no components that provide a strong positive prediction of a company entering the nuclear sector. Model 2 of Table 7 removes the effects of the overall number of certificates, so that the coefficients can be more easily compared[51]. Companies that produce plastic pressure valves and portable water heaters are found to be more likely to have a nuclear related certification. However, when accounting for the effect of adding any new certificates, the individual certificate type affects are nominal. This means that the size of a company is more determinative of being able to enter the nuclear manufacturing sector than the specific type of products they manufacture. This supports the assumption that all small component manufacturers have some ability to enter the nuclear market in the long run.

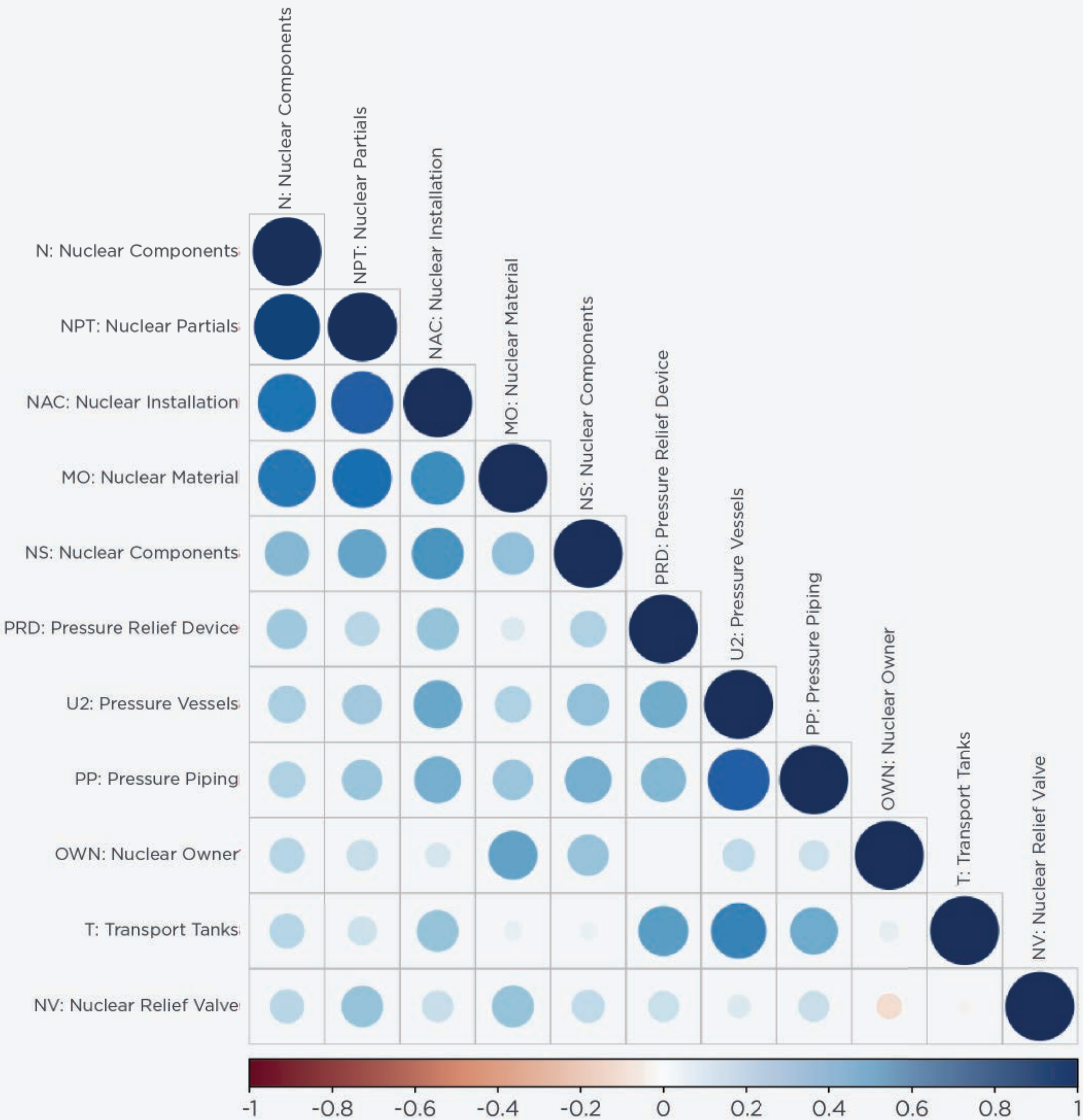
Expanding upon the dynamic of nuclear and non-nuclear certification rates, a correlation matrix of certificates is provided in Figure 10. This figure visualizes the relationship between the number of certificates issued each year, rather than identifying co-production at the firm level.

All but 6 of the 34 certification types are positively correlated with nuclear components.[52] Across time, general manufacturing rates are positively associated with nuclear component manufacturing. The set of nuclear ASME certificates show the strongest correlation with each other. There are nuclear related time trends in production that link these components, but there is also a generalized manufacturing effect shared with all other certificates.

[51] In model one, the total effect of a certificate is the sum of the "Number of Cert." coefficients and the unique certificate type coefficient. The significance value for the unique coefficients is relative to zero when accounting for the general effect.

[52] See Appendix (H) for a correlation matrix of all components.

Figure 10:
Correlation Matrix of ASME Certification Levels (Ibid supra 19)



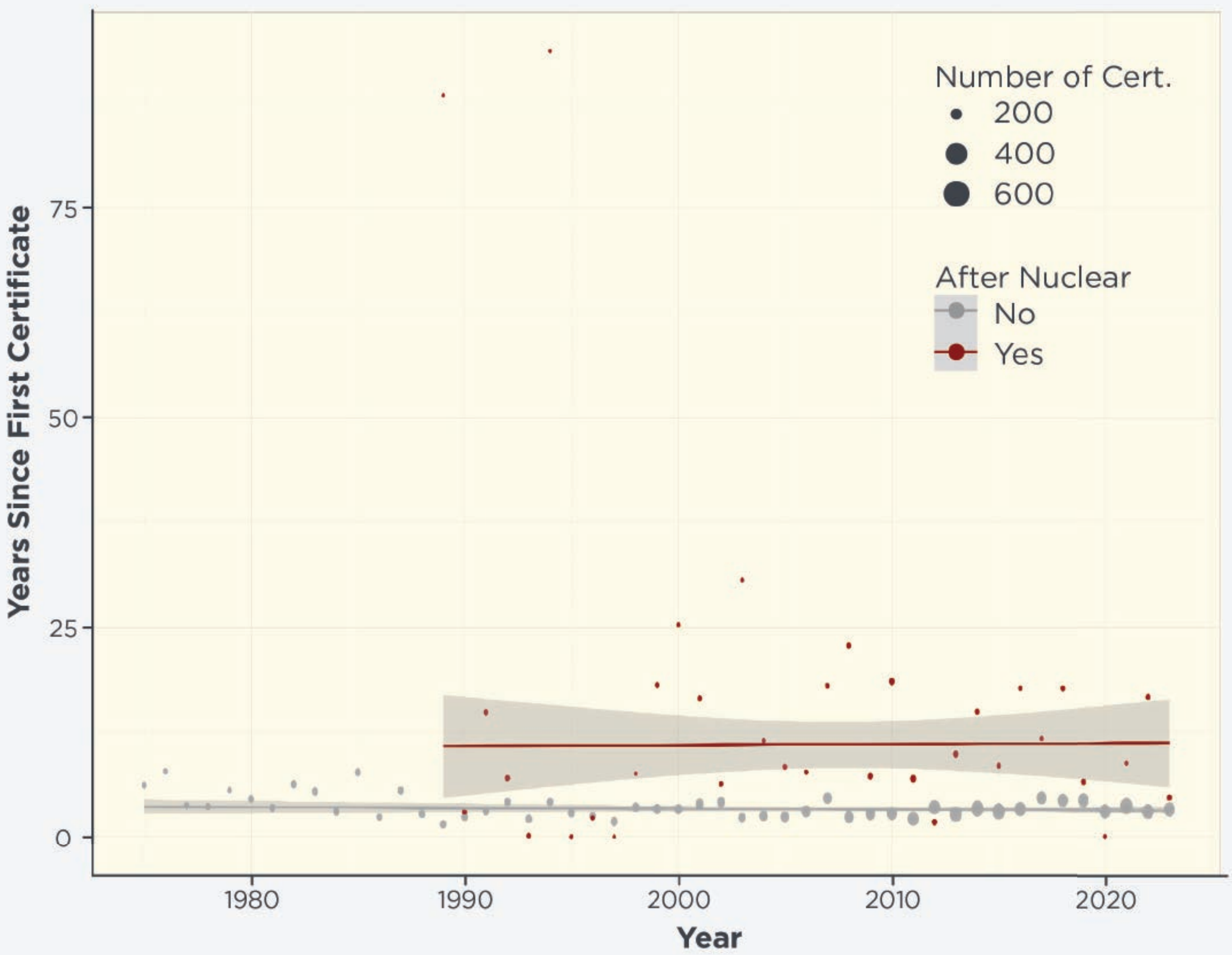
The logit results also suggest that nuclear firms are older than average. This conclusion is consistent with the theory that nuclear component manufacturing is undertaken by large, well-established firms choosing to diversify output. However, an alternative explanation of these results is that nuclear companies entered the market at an earlier date due to the expansion of nuclear power use in the 1970s. To supplement the results in Table 7, a graph of the age of firms based on the certificate type is provided in Figure 11. The first issuance date of an ASME certificate identified for each company in the dataset. Then, the difference between this first issuance date and the year other certificates were issued is calculated. The figure groups this difference by year and separates companies involved in nuclear component manufacturing (in red) from all other producers (in grey). This provides an apples-to-apples comparison by removing the year selection effect. The regression lines are weighted by the number of certificates issued each year.

Both regression lines are nearly horizontal, but staggered, meaning that nuclear components certificates are produced by companies that are on average 12 years older than the average company. There are no time trends in firm age for either group. This corroborates the logit model results that nuclear component manufacturing is undertaken by older, well-established companies.

Summary

The firm composition analysis supports a score of *moderate advantage* in the small components manufacturing sector. Small nuclear component manufacturing is taken up by established firms as opposed to startups. This implies the location of established non-nuclear manufacturing firms influences the location of future nuclear component production. On this front, Wyoming has the most manufacturing GDP per capita of any state (U.S. Bureau of Economic Analysis, 2005; US Census Bureau, 2023). The existing manufacturing sector in Wyoming contributes parts for power generation, oil and gas production, and mining. Firms in these sectors are more likely to select nuclear components as a future production line due to portfolio diversification, overlapping skills, and capital requirements. A recent example of this is the entrance of L&H into the nuclear component industry, which began by producing components for the oil and gas, and coal mining sectors (Hurst, 2014; L&H Industrial, 2023). When these firms enter the nuclear sector, they maintain existing product lines, but switch future development into the nuclear sector. If nuclear power production expands, the established firms in the State are well positioned to adopt nuclear components by entering the nuclear market.

Figure 11:
Maturity of Companies Acquiring Certificates Each Year. (Ibid supra 20)



3.3 TAX STRUCTURE

Large Components	Small Components
Major Advantage	Major Advantage

Tax Structure: Scoring Criteria

The Wyoming tax structure is scored as a *major advantage* for establishing a nuclear manufacturing sector in the State because Wyoming not only has one of the lowest tax rates in the country, but also provides incentives for manufacturers.

Empirical analysis shows that corporate tax rates are a major consideration for attracting new manufacturing. An econometric model of the number of ASME certified manufacturers estimates that for every 1% decrease in the tax rate, a state can expect 0.3% additional nuclear-grade product lines. Since Wyoming has the lowest effective tax rate for established manufacturers, this is a *major advantage* for economic development of the industry.

Tax Structure: Analysis

There are multiple attributes of the Wyoming tax code that are notable for nuclear component manufacturing. The State levies a sales tax of 4%, which is lower than all but seven other states. Wyoming is one of sixteen states with a capital stock tax, currently set at $0.0002 per dollar of asset (Wyoming Taxpayers Association, 2020). However, manufacturing machinery is exempt from both sales and capital stock tax (Wyoming Department of Revenue, 2023). For property taxes, a component manufacturing facility falls under the classification of industrial private property, which has a tax base of 11% (Wyoming Taxpayers Association, 2022). Under the Wyoming tax code, property tax rates are adjusted based on the annual cost of operating government programs. This adjustment is referred to as the mill levy and the most recent state average was 0.068 (Wyoming Taxpayers Association, 2022). Importantly, Wyoming is one of only three states to have no corporate income tax.

Not all manufacturers are impacted equally by these tax codes. Property and use taxes are assessed based on capital stock rather than profit. Smaller experimental firms have low present profits, but with the expectation of future growth. This leads to a scenario where manufacturers may face different effective tax rates on profit. After accounting for all exemptions, a benchmark capital intensive manufacturing facility is estimated to pay an effective tax rate of 5.85% if they are well developed, but 11.25% if they are in the first ten years of production (Tax Foundation, 2021). Analysis in Section 3.2 demonstrates that nuclear component manufacturers are significantly larger and produce more diverse products than the average manufacturing firm. This means a typical nuclear component manufacturing company can take full advantage of the Wyoming tax benefits and expect to pay a 5.85% effective tax rate.

These estimates are combined with the results from Table 4 to determine how the Wyoming tax code advantages nuclear components manufactures. This regression estimates that nuclear manufacturing certification decreases by 0.31% for every 1% increase in corporate tax rate. The median effective corporate tax rate for established manufacturing firms in the U.S. is 13.44%, and 12.1% for a developing manufacturing company (Tax Foundation, 2021). Compared to the national median tax rate, the Wyoming tax code is expected to increase the number of active nuclear component lines by 2.35% for established firms, but only 0.26% for new firms. The upper bound estimate for established firms is a 4% increase[53], with a lower bound of a 0.71% increase.

Summary

The Wyoming tax code provides a distinct advantage to established manufacturing firms, such as those in the nuclear component industry. These advantages not only allow for continued economic development, but provide a unique draw to Wyoming over comparable states. These benefits apply equally to small and large components and so both scores are in the *major advantage* range.

[53] at a 95% confidence interval.

3.4 TECHNOLOGY

Large Components
Major Obstacle

Small Components
Minor Advantage

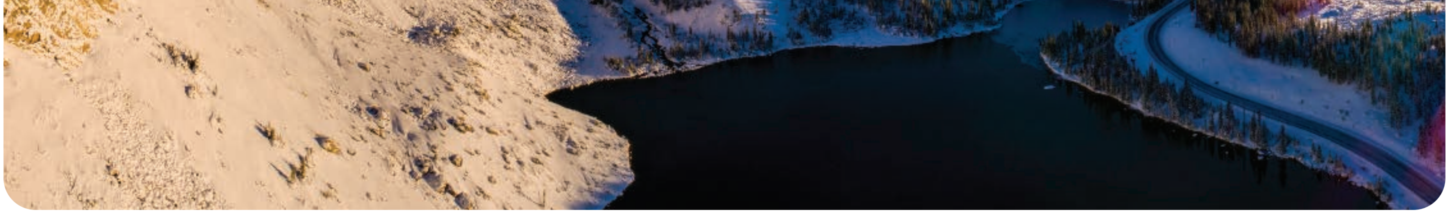
Technology: Scoring Criteria

Innovations in manufacturing methods and in nuclear power plant design contribute to the prospects of nuclear manufacturing in Wyoming. Large components require significant capital; but this constraint can be lifted by either developing modular manufacturing methods or by reducing reactor size through SMR development. If large nuclear components are to be produced in Wyoming, this technological innovation is necessary, placing the score as a *major obstacle.*

The current state of technology is amenable to establishing small component nuclear manufacturing in Wyoming because existing advanced manufacturing methods can be adopted for nuclear component production. Under the current path of innovation and adoption, small components manufacturing output will increase. This is a generalized effect and technological changes are unlikely to increase manufacturing rates in Wyoming more than other states. Therefore, the technological score for small components is a *minor advantage.*

Technology: Analysis

Technology limitations affect nuclear component manufacturing through both supply and demand. On the supply side, innovative manufacturing methods and materials can decrease costs. Modular construction methods will affect which designs are capable of being constructed in the State by reducing the economies of scale required. On the demand side, innovations in nuclear reactor designs and standardization change which components are produced. Long-run cost reductions form from learning through experience which will make advanced designs more economical, consequently increasing the demand for all nuclear components. Continued innovation in SMR technology therefore contributes to the prospects of establishing a Wyoming nuclear manufacturing industry.



Supply Technology- Advanced Manufacturing Methods

New advanced manufacturing Technologies (AMT) have demonstrated the potential to produce many high-quality safety-related SSC's faster and more economical than traditional methods. Further, some proposed SSCs planned for advanced SMRs, and power reactors operate at extremely hot temperatures and require some components to have high specific tolerances and reliability standards that are difficult to achieve using currently approved manufacturing methods. The scope of AMT includes new analytic / numerical methods, improved non-destructive examination (NDE) techniques, and advanced manufactur-ing methods.

Use of advanced numeric and empirical modeling has shown potential for reduced SSC testing and development of more resilient components. A summary of current proposed advance modeling is shown in Table 8.

Table 8:
Current Advanced Modeling (Jacob et al., 2020)

Technique Application	
Grain-level meso-scale models for material structural deformation during manufacturing and solid phase processing	• Potts Model Monte Carlo • Phase field models • Crystal plasticity
Component-level models	• Finite element (Solid mechanics; Fracture mechanics • Smoothed particle hydrodynamics
Models to bridge and connect scales	• Physics-informed machine learning models • Processing material microstructure predictions
Predict thermodynamics for materials selection	• Material lifecycle kinetics, properties
Atomistic models for irradiation damage and performance	- Density functional theory - Molecular dynamics - Atomistic Kinetic Monte Carlo

The NRC requires the integrity of certain safety related SSCs to be extensively non-destructively examined[54] during manufacturing, construction, and operation (Nuclear Regulatory Commission, 2023a). Several advanced NDE technologies have been developed but have not been incorporated into the ASME Code. These advanced methods are listed in Table 9.

Table 9:
Proposed Advanced NDE Techniques and Resources (Sullivan, 2004)

Photon-based interrogation techniques (microtomography for micro-structural)	Dielectric spectroscopy	Micro/mm-waves
Computational modeling of physical processes on inspection sig-nals	Digital radiography	Irradiated component trans-mission radiography & emission tomography
Acoustic microscope	Time and frequency domain electrometry	Mechanical testing includ-ing load frames and ovens
Linear and nonlinear ultra-sonic techniques	Ultrasonic laser imag-ing	Infrared thermography

54 ASME Code specifies radiographic, magnetic particle, dye penetration, ultrasonic examination, eddy current NDE & NDT methods and examiner qualifications (American Society of Mechanical Engineers, 2024).

There are proposed pilot projects in the following AMT methods for nuclear components (Electric Power Research Institute, 2021; Nuclear Energy Institute, 2019; Nuclear Regulatory Commission, 2021c):

1. Powder Metallurgy-Hot Isostatic Pressing,
2. Directed Energy Deposition,
3. Laser Powder Bed Fusion,
4. Electron Beam Welding (up to 10ft diameter),
5. Advanced Cladding Processes (diode laser cladding, cold-spray & laser assisted cold-spray fric-tion additive stir, diffusion bonding), and
6. Other advanced welding techniques, machining techniques, surfacing technologies.

These technological innovations have the potential to affect the manufacturing market by changing the quality and price of components. Yet AMT processes are already used by other industries, so financial support in research and development is not essential to continue to progress.

Demand Technology- Small Modular Reactors

Small modular reactor technology has economic interconnections with the components manufacturing market. SMR large components are more likely to be produced in Wyoming than the largest components in traditional designs, so this innovation is relevant to the prospects of the State. Large international facilities are cost effective primarily due to economies of scale, and government support, but SMR has an advantage in repeated production instead of scope. Increasing SMR output could reverse the trend of large components manufacturing moving overseas by making existing U.S. facilities more cost competitive. Another effect of improved SMR design is a consistent source of demand for nuclear components. The production of many small nuclear reactors would create a steady need for manufacturing, rather than the current situation where a single large reactor is built every decade. In turn, this reduces the financial risk of investment in nuclear component manufacturing.

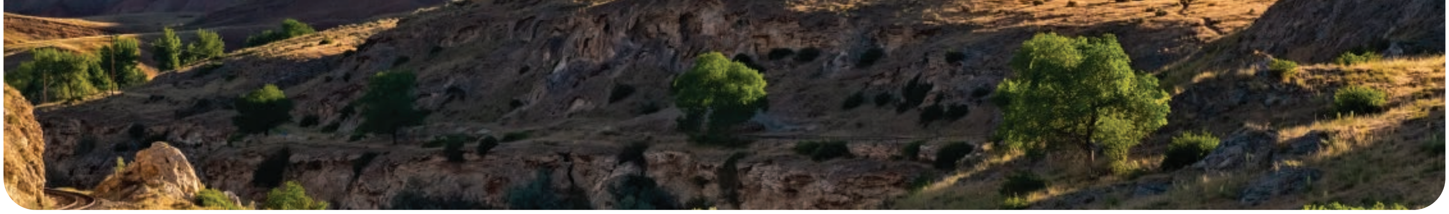
While SMR production can affect the market, technological innovation is essential for these designs to be cost effective, and knowledge gained from experience will play a significant role. There is significant research interest in bringing down production costs of SMR designs, with recent models estimating that technological innovation is required to reach a market ready state (Kozeracki et al., 2023; Mignacca & Locatelli, 2020). Often, technological constraints limit technological development until a critical mass of experience is acquired (Arrow, 1962). Learning through experience is especially relevant to SMR design where the learning curve is steep (Carelli et al., 2010; Stewart & Shirvan, 2022). This technological obstacle to development is difficult to overcome since innovative

technology is not cost effective until the knowledge base matures, but no knowledge base is developed until the technology becomes cost effective. Recently, the Wyoming Energy Authority (WEA) provided $1 million of funding for micro reactors applications in extractive industries (BWX Technologies, 2023; Wyoming Energy Authority, 2023). The State is also involved in the Intermountain-west Nuclear Energy Corridor promoting SMR projects in the Wyoming (U.S. Economic Development Administration, 2023b). These projects will promote experience in SMR application and help reduce these barriers to entry for future projects.

Summary

Large nuclear component manufacturing requires sizable upfront capital investment to be feasible, which severely restricts the opportunities to develop such a facility in Wyoming. This restriction can be mitigated by either improving manufacturing methods to allow modular construction, or by reducing the size of large components through SMR adoption. Without continued research and development large components manufacturing will require significant financial support to be viable in Wyoming, resulting in scoring technology as a *major obstacle.*

In contrast, small components are being produced more efficiently using advanced manufacturing methods. Many of these methods are not limited by technology, but are instead held back by legal considerations (see Section 3.6). Manufacturing methods, such as 3D printing, are used widely in other industries and can improve manufacturing efficiency in the nuclear sector. Under the status quo, the uptake of technology in the industry will increase the profitability of component manufacturing firms. This generalized effect improves the prospects of attracting nuclear component manufacturing to Wyoming, but not distinctly more than other states. For this reason, the small component score is a *minor advantage.*



3.5 LOCATION

Large Components	Small Components
Minor Obstacle	Minor Obstacle

Location: Scoring Criteria

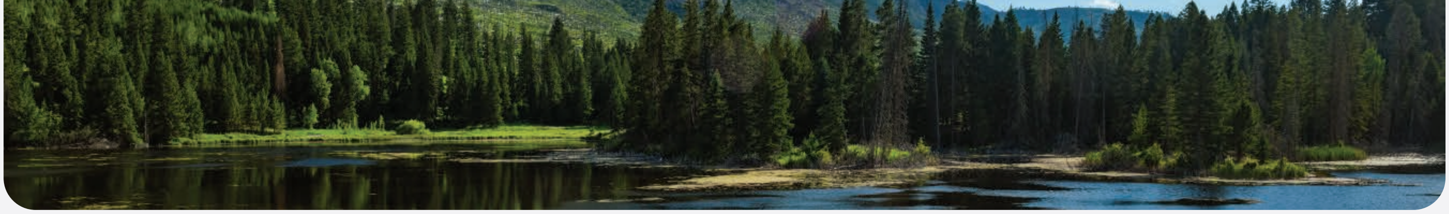
Location is identified as a *minor obstacle* for nuclear manufacturing firms seeking to locate within Wyoming. This score is the most sensitive of any of the estimates and may range from a *minor obstacle* to a *minor advantage*.

The combined effects of location factors are mixed and do not provide a significant hinderance or promotion of nuclear component manufacturing. While Wyoming has a robust energy generation sector, low natural disaster rates, and temperate summers, there is also extreme snow and wind in the winter, low population density, and currently, no nuclear power produced in the State. The score of *minor disadvantages* is expected to increase to *minor advantage* if nuclear power continues to be fostered in Wyoming. A key policy consideration is that the factors that allow nuclear power production to flourish in a state also promote nuclear component manufacturing. Providing sufficient infrastructure and creating a business climate amenable to nuclear produced electricity development improves the prospects of manufacturing in the State.

Location: Analysis

Various considerations influence the location decisions of manufacturing facilities. A few of the factors relevant to location choice include electricity costs, distance from raw materials, weather, unionization rates, tax rates, available infrastructure, environmental sustainability, and education levels (Chen et al., 2014; Epping, 1982; Mardikoraem, 2016). The relative importance of these attributes depends on the traits of the manufacturing company. Foreign firms are found to rank transportation logistics, trade availability, and community environment highly, whereas U.S. firms historically make location decisions based on tax rates and state incentives (McConnel, 1980; Newman & Sullivan, 1988; Ulgado, 1996). High tech manufacturing is more sensitive to climate considerations[55] and large firms are less sensitive to wage rates (Schmenner et al., 1987). Similarly, transportation infrastructure has been identified as a driver of manufacturing firm growth, but the scale of the effect is dependent on the type of goods produced (Hall et al., 2017).

[55] The argument made is that higher paid employees are willing to trade off income for amenities such as comfortable weather. This makes manufacturing depended on highly educated employees more likely to locate in comfortably warm regions.



Related firms tend to collocate creating regional economic nodes. A feedback loop can occur whereby production costs decline as an economy becomes more specialized (Porter, 1998). For example, a cheese producer prefers to locate near the dairy farm that supplies milk. Likewise, the dairy farm gains an advantage by purchasing farmland near the cheese producer. Over time, this feedback forms local economies where a set of related goods are produced. These agglomeration effects are also promoted by knowledge spillover and network effects. Similar knowledge-based drivers are most important in industries, such as nuclear electricity production, where experience reduces production costs. In fact, clustering is most consistent in sectors where technological development improves efficiency (Audretsch & Feldman, 1996). While the concept of industry clustering provides a framework for regional economic development, the theory cannot be applied in all circumstances since there are also advantages to regional industry diversity (Martin & Sunley, 2003).

There is evidence that nuclear manufacturing develops alongside nuclear power plants, adhering to this regional clustering model. This relationship is explored visually before applying an econometric model that quantifies these dynamics. Figure 12 shows the distribution of nuclear manufacturing facilities[56] overlayed by electricity production. Since the drivers of firm location are dependent on the form of manufacturing being evaluated, the data is broken into two segments. On the first row of Figure 12, the level[57] of non-nuclear related ASME certificates are shown in the purple map. The red map presents the nameplate capacity of all active power plants. On the second row of Figure 12, the purple map displays the number of ASME certifications for nuclear components, and the red map displays the nameplate capacity of nuclear power plants[58].

Trends emerge by comparing each of these maps. One trend is that nameplate capacity is spatially correlated to non-nuclear ASME certification rates. Many states with high nameplate capacity likewise have above average ASME certification rates, such as, Wyoming, Oklahoma, and North Dakota. Manufacturing firms require large inputs of electricity so there is an advantage to locating near electric power plants. There are also non-casual, but important, spatial connections. For example, land prices, weather, and state tax rates affect both the industrial manufacturing and power generation sectors. However, this dynamic does not hold for nuclear component manufacturing. The total nameplate capacity of a state is a weak indicator of the number of nuclear component manufacturing certificates.

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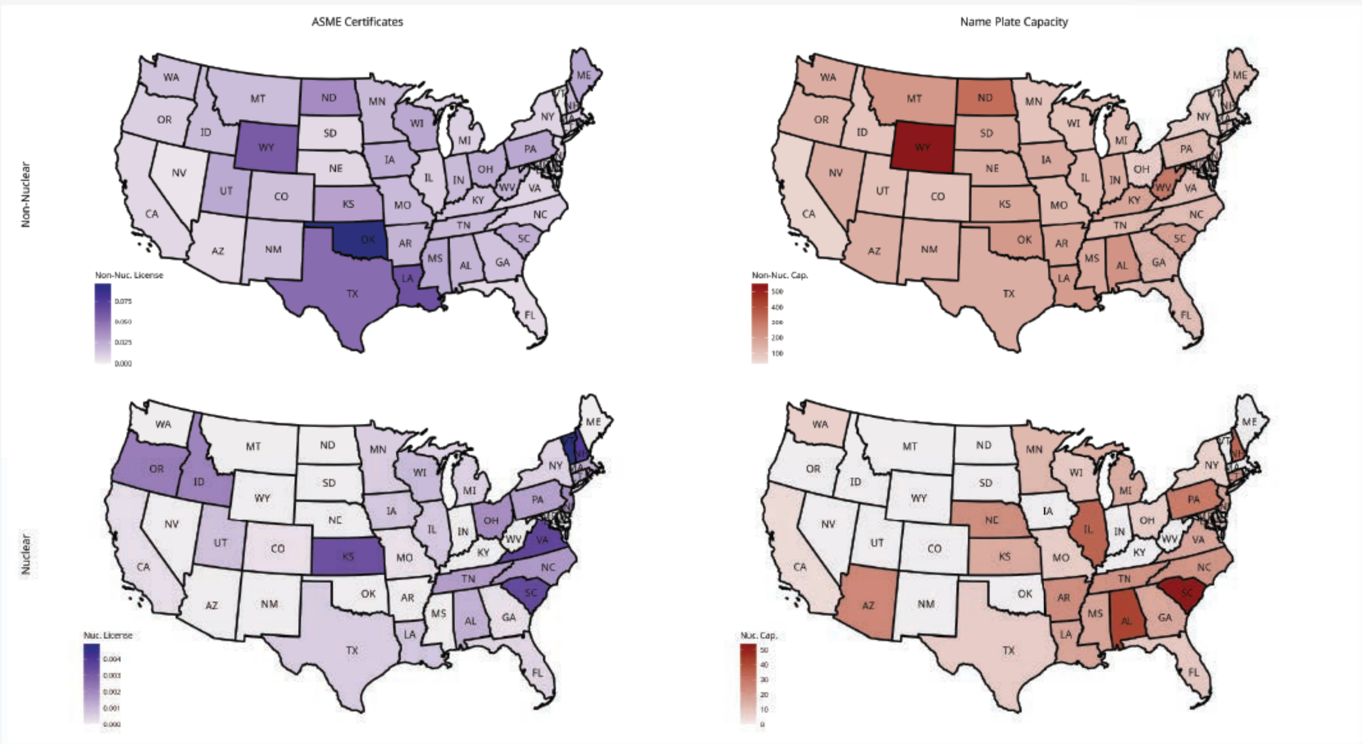
56 These are only firms that invest in certifications through ASME. This selects for manufacturing firms that invest in specialized knowledge to attract customers that require dependable components. The distribution of all manufacturing may vary from these maps, but this type of firm is more applicable for nuclear industry analysis.

57 All values in the map are population weighted.

58 All maps are scaled to sample size. The same shade of color correspond to fewer certificates in the nuclear maps since there are fewer n-stamps than the combination of all other certifications.

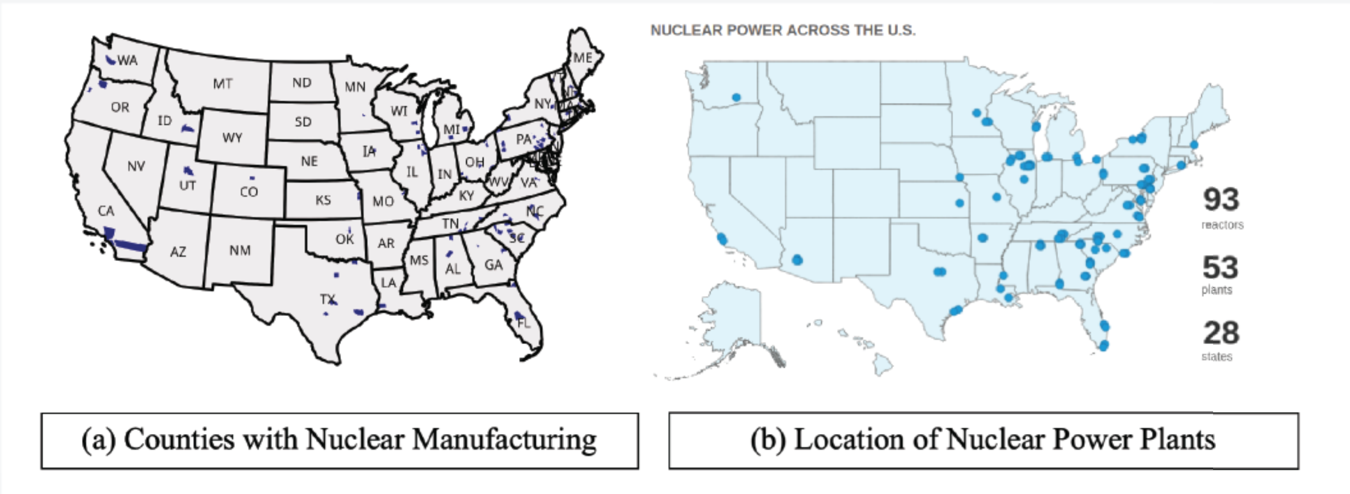
Figure 12:
Population Weighted Manufacturing and ASME Nuclear Type Certificates[59]



However, there exists a notable correlation between the location of nuclear component manufacturing and nuclear nameplate capacity. There is a high density of nuclear power plants in the East Coast corridor, such as South Carolina, North Carolina and Virginia, that is shared by nuclear components manufacturing. To explore this dynamic, *Figure 13* identified the counties where ASME nuclear certified facilities are located, and the exact location of nuclear power plants.

59 Nameplate capacity data comes from (Energy Information Administration, 2023d). ASME certificate data collected with the process explained in Appendix (A). Population data used to weight results provided by (US Census Bureau, 2023).

Figure 13:
Location of Nuclear Component Manufacturing Facilities and Nuclear Power Plant[60]



The spatial collocation is more pronounced at the county level. In large states, the counties with nuclear component manufacturing tend to be near existing power plants. For example, Texas manufacturing facilities and power plants are both located in the east. The figure also provides information about manufacturing near state borders. Even though Nebraska has no nuclear component manufactures, the operating nuclear power plant in the State is close to component manufactures proximate to its boarder with Kansas.

A final map is provided in Figure 14 which shows the locations of the companies that supplied components for the most recent U.S. nuclear power plant, Vogtle units 3&4. Vogtle unit 3 began operation in 2023 and Vogtle unit 4 is scheduled to begin operation in late 2024.

[60] Figure 8b source (Nuclear Energy Institute, 2023).

Figure 14:
Location of AP1000 Component Suppliers[61]

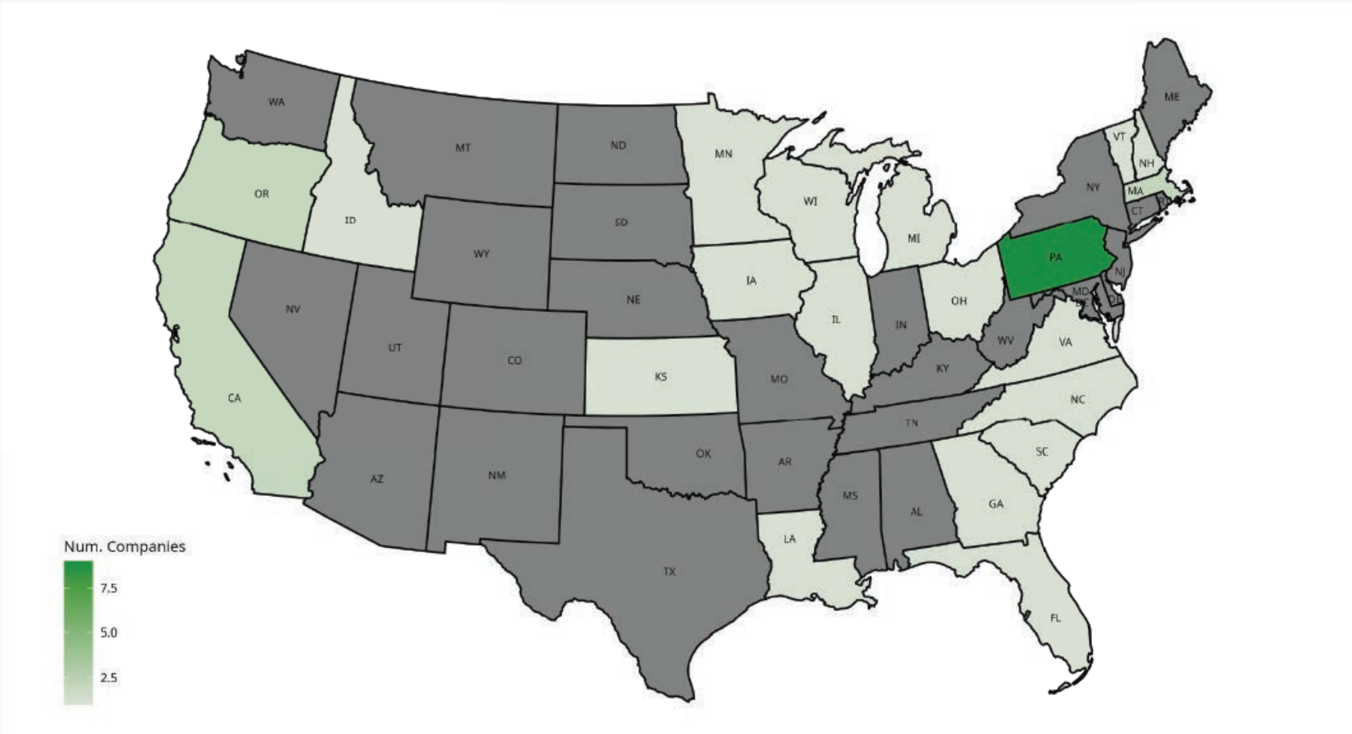


Figure 14 provides a snapshot of the most recent market conditions and can be compared to the ASME data set which captures a longer period. The AP1000 component manufacturing locations are more evenly distributed. Pennsylvania is an outlier with four different companies supplying nuclear components to the project.

In the next phase of analysis, the dynamic of these relationships was evaluated econometrically, by applying the Poisson fixed effect regression model as presented in model 3 of *Table 4.* This model improves the spatial correlation analysis by estimating the magnitude of varied factors. This model includes only year fixed effects, leaving out state fixed effects, allowing the model to estimate the effect of state characteristics on nuclear component certification[62].

61 Data collected from (Department of Energy, 2022).

62 The cost of leaving out the state fixed effects is that it omits variables that are constant in each state bias the model if they are correlated with one of the included variables. Controls like population, should be viewed as capturing the effect of all omitted variables that move in tandem with population.

For ease of analysis, a summary of the most pertinent location specific variables is included in *Table 10*. The direction of each identified effect meets expectations. States with more electricity generation, population, and manufacturing employment attract nuclear component manufacturing facilities. All else equal, severe weather reduces the number of manufacturing facilities in a state.

Table 10:
Summary of Location Effect Estimates

1% Increase In:	Direction of Effect	Estimate	Lower Range (2.5%)	Upper Range (97.5%)	P-Value
Nuclear Capacity	+	0.08%	0.01%	0.15%	0.03
Other Capacity	+	0.30%	-0.63%	1.23%	0.53
Natural Disasters Deaths (Avg. count per year)	-	-0.54%	-1.20%	0.12%	0.11
Heating Degree Days (Avg. count per year)	-	-0.53%	-1.67%	0.60%	0.357
Cooling Degree Days (Avg. count per year)	-	-0.48%	-1.81%	0.85%	0.482
Population	+	0.34%	-0.82%	1.50%	0.57
Manufacturing Employment	+	0.78%	0.08%	1.48%	0.029

A 1% increase in nuclear capacity is predicted to increase the number of manufacturing certificates by 0.08%. While this is a low conversion rate, the relative effect is largest for states with no existing nuclear capacity. Construction of the 345-megawatt TerraPower project in Kemmerer will have a larger effect than the same increase in a state like South Carolina which already has significant nuclear power generation.

Existing energy production in Wyoming may encourage nuclear manufacturing. The predicted effect of a 1% increase in electricity capacity is a 0.3% increase in component manufacturing lines. However, the data is not consistent enough to rule out that this result is caused by randomness. This means there is not enough statistical evidence to conclude that non-nuclear power generation contributes to nuclear manufacturing location choice. This corroborates the analysis in *Figure 13*, suggesting that nuclear power plant location is weakly correlated with energy production.

Turning to environmental factors, extreme weather is predicted to decrease the number of active nuclear component manufacturing certificates. Data on the number of direct deaths from natural disasters were compiled from the NOAA datasets (*National Oceanic and Atmospheric Administration, 2023a*). For every 1% increase in the number of natural disaster deaths, the number of expected certificate holders decreased by 0.54%[64].

Heating degree days and cooling degree days are a measure of uncomfortable weather. A heating degree day is the number of degrees Fahrenheit below 65 degrees. As past literature has explored, the comfort of a climate can influence the location of specific industries (*Schmenner et al., 1987*). A 1% increase in either heating degree days or cooling degree days reduces N-stamp certification rate by approximately 0.5%.

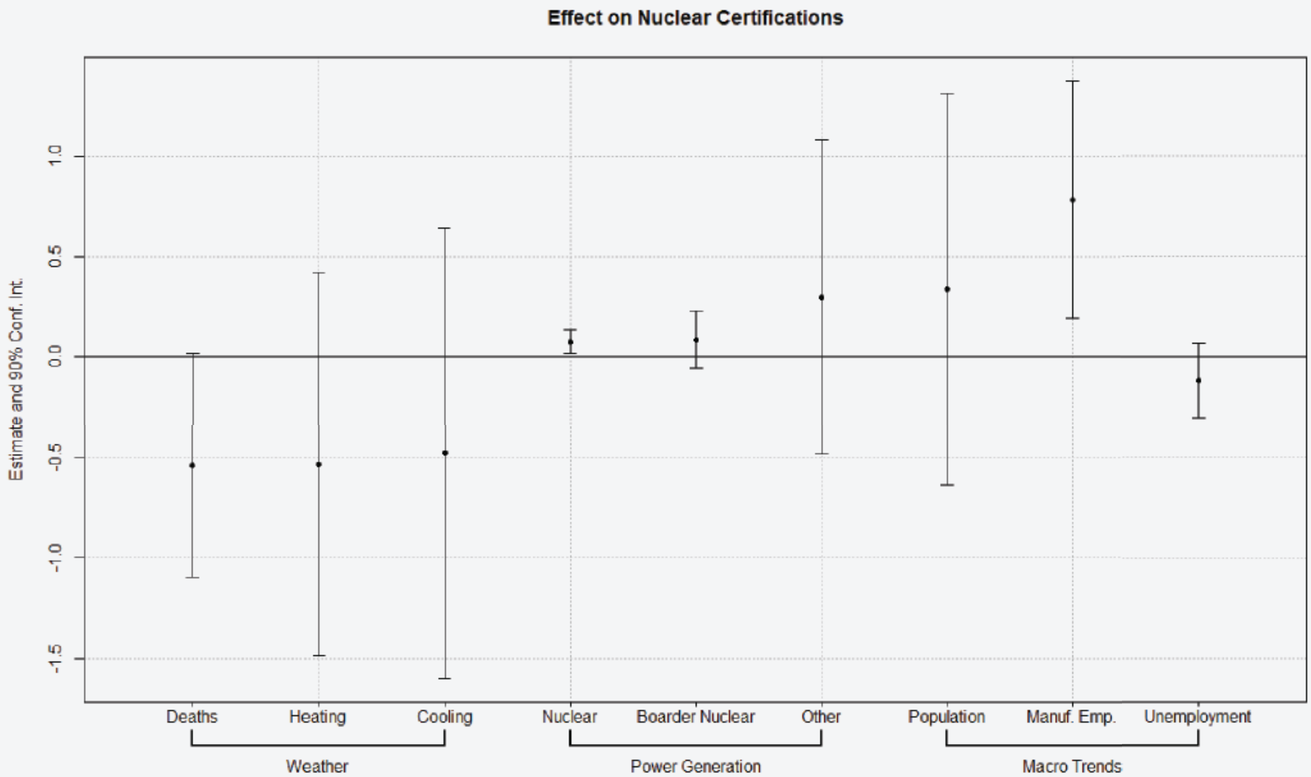
Of the estimated attributes, manufacturing employment has the largest magnitude. For every 1% increase in manufacturing employment, a state can expect 0.78% more nuclear manufacturing certificates. This variable captures unobserved state level attributes correlated with manufacturing employment, such as available infrastructure. The hypothesis that manufacturing employment levels correlate one-to-one with nuclear certification levels cannot be rejected[65], suggesting that the same state attributes that encourage total manufacturing employment equally promote nuclear component manufacturing. While the State does have high per capital levels further development of manufacturing will improve the feasibility of acquiring nuclear manufacturing. Population is found to have a positive effect on the number of ASME N-stamp certificates, but the effect is weak when controlling for manufacturing employment.

64 These results are significant at the 11% level. This is just above the standard 10% threshold for statistical significance.

65 This was formally evaluated with a F-test.

Each of these estimates are grouped into categories, and the coefficients are plotted along with confidence intervals[66] in *Figure 15.*

Figure 15:
Location Effects on Nuclear Component Certification
(visual representation of results of table 1)

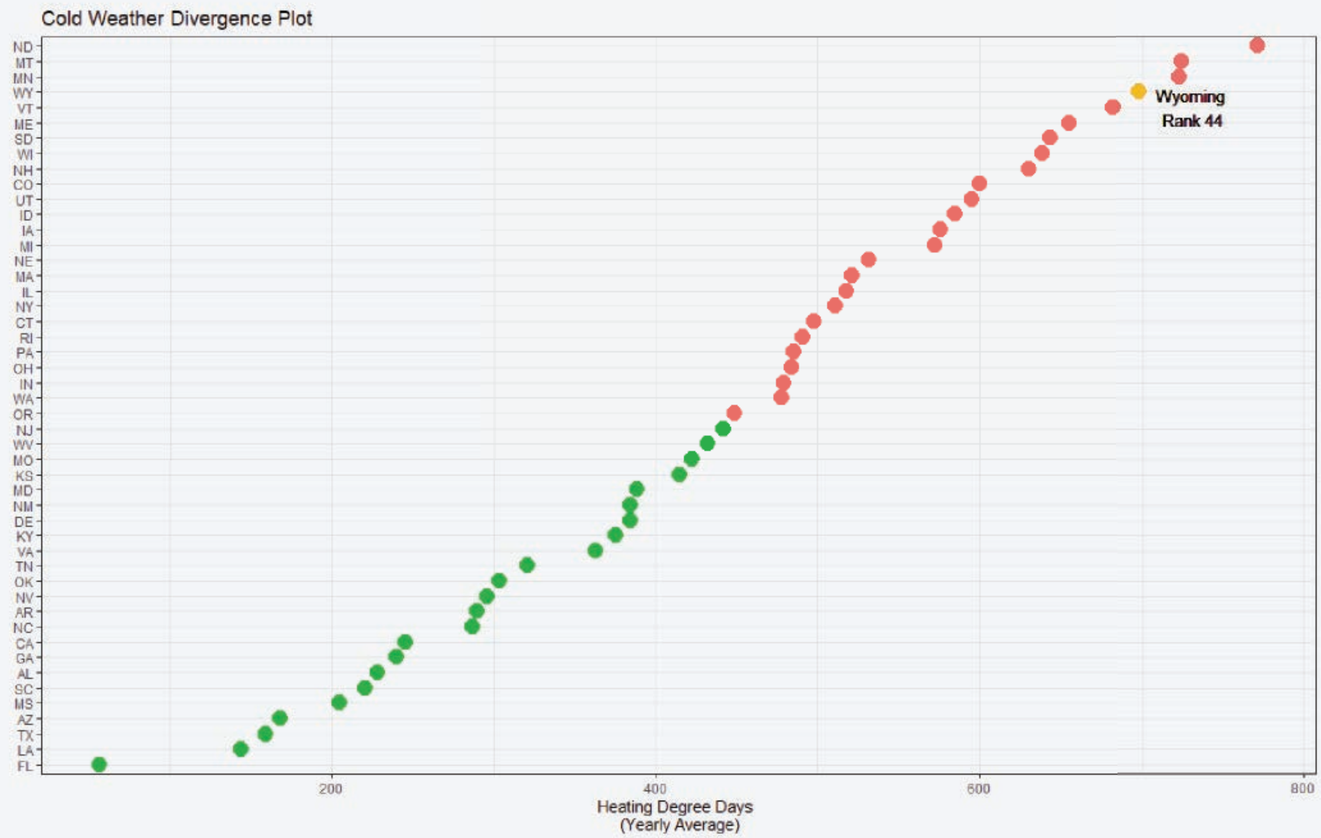


This figure provides a clear picture of the magnitude and precision of each estimate. It shows that all weather-related variables have similar predicted effects. Similarly, nuclear power output has a comparable effect to the nuclear power generated by neighboring states, but the in state nuclear power product estimate is more consistent. While the effect of overall power production is positive, there is a large variance, and the results are not robust enough to verify the relationship.

In order to apply these results, *Figure 16, Figure 17,* and *Figure 18* plot the value of each weather variable per state. States that have an above average nuclear manufacturing rate due to the weather variable are labeled in green where states that have a below average outcome are labelled in red.

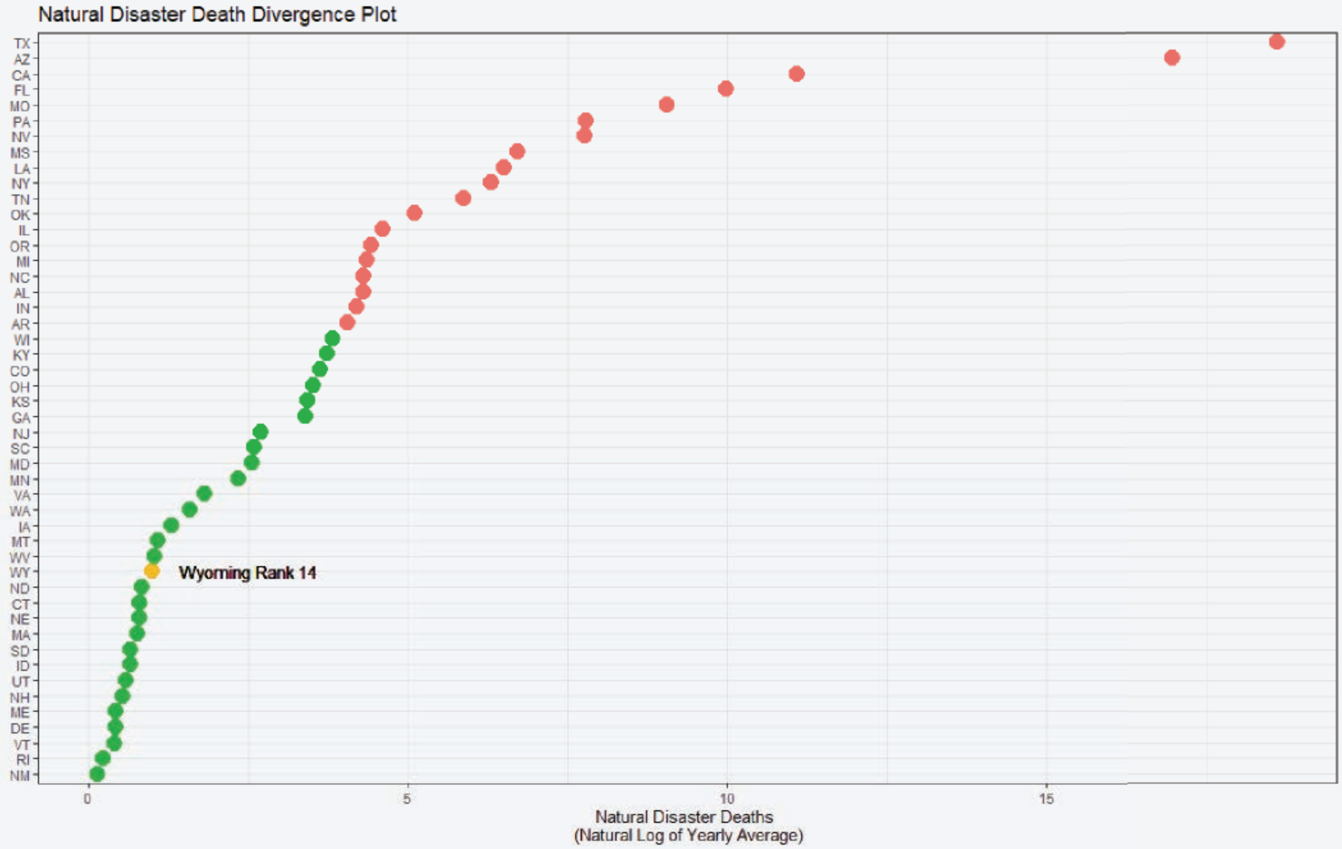
66 The confidence intervals show the range of coefficients that might be accurate. Accounting for normal randomness in the data the real coefficient will fall outside of this range only 10% of the time under the model assumptions.

Figure 16:
Wyoming Natural Disaster Rank[67]



[67] Data used to create Figure 16 comes from (National Oceanic and Atmospheric Administration, 2023b).

Figure 17:
Wyoming Cold Weather Rank[68]



[68] Data used to create Figure 17 and Figure 18 comes from (National Oceanic and Atmospheric Administration, 2023a).

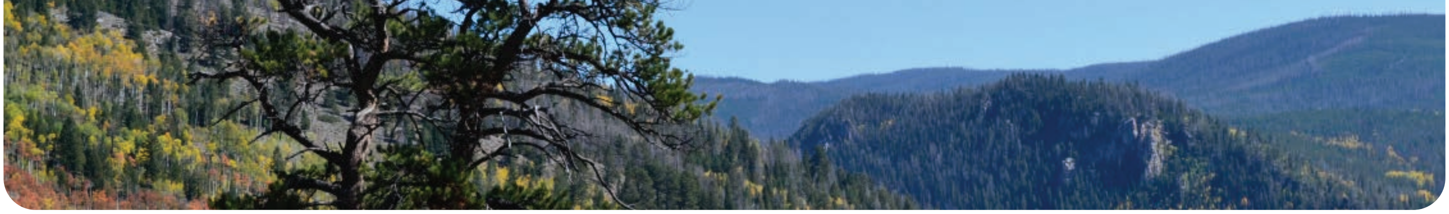
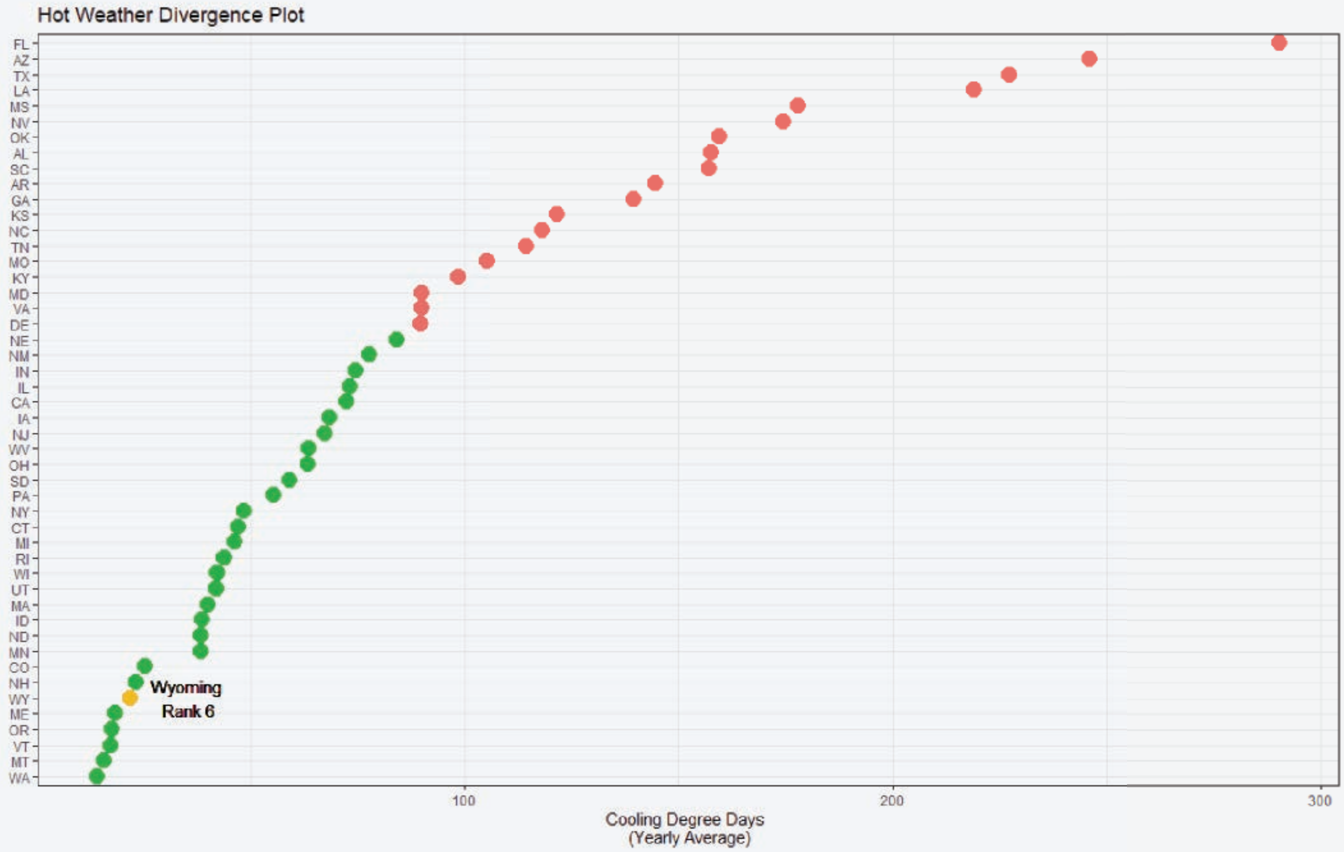


Figure 18:
Wyoming Hot Weather Rank



Summary

Wyoming has significantly lower than average extreme hot days and natural disaster deaths. This is counteracted by the number of extremely cold days. Taken holistically, the location of Wyoming is found to be a *minor disadvantage.* The State has high relative levels of manufacturing employment and low natural disaster death rates. A growing nuclear power production industry in Wyoming is indicative of the State's ability to expand the nuclear components sector in the future. However, this progress is not guaranteed as evidenced by the recent cancellation of six SMR reactors slated to operate in Utah (*Cho, 2023*). Therefore, the current score does not assume that this capacity will continue to develop. If Wyoming nuclear capacity expands, the predicted location effects that encourage development will outweigh the forecasted hampering effects. This places the present scoring in the *minor barrier* range with a clear path to improve to a *minor advantage.*

3.6 LEGAL

Large Components
Minor Obstacle

Small Components
Minor Obstacle

Legal: Scoring Criteria

Federal policy directly affects the viability of nuclear components manufacturing, because safety-related component are required to meet stringent quality control standards, adding to costs. This entails engineering work, as well as setting tight manufacturing tolerances. Non-safety components costs are also affected by this legal standard because the failure of these parts must be shown to have no impact on the safety components.

Small non-safety components have little cost additions from regulation, but safety related components face technological restriction and significant added quality assurance (QA) costs. Overall small components are scored as facing a *minor obstacle*. The added costs associated with regulations are substantial for small components, but these costs do not burden Wyoming firms more than other States. Innovation in reactor design and manufacturing methods have the potential to change the manufacturing market of large nuclear components. The regulatory structure places an emphasis on design safety, making innovation more costly. Because of this, large components are deemed to face a *moderate obstacle* from legal obligations.

Legal: Analysis

The NRC has responsibility for licensing and regulating the nation's civilian use of radioactive materials. This responsibility includes promulgating and enforcing rules for the design, traceability, manufacture, storage, testing, and use of certain classes of SSCs used in nuclear applications. Components are classified into three legal categories: *industrial grade, important to safety, and safety related* (SR). The legal barriers for each category of part differ based on the assigned classifications.

Industrial components face the lowest regulatory hurdles to manufacturing. These components are identified as being used only for non-nuclear applications, such as the power conversion system. Most of these components are highly specialized, and therefore, are only manufactured by a few well-established suppliers. For example, almost all domestic nuclear power plants use either a Westinghouse or General Electric power conversion system (turbine-generator). Typically, non-specialized industrial components make up less than 1% of the total SSC procurement costs for a nuclear power plant[69].

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[69] Table 16 in Appendix (B) lists the small industrial-grade components that are typically used in non-SR applications.

From an economic perspective, industrial-grade component manufacturing should be broadly evaluated within the demand of all industrial applications, such as refineries, mining equipment, fossil power plants, windfarms, and data centers.

However, *industrial components* are not free from regulatory costs. NRC Rules require that license applicants demonstrate that the failure of any industrial-grade component will not adversely affect the function or qualification of SR SSCs. For example, analyses must show that the collapse of an industrial grade component following an earthquake will not prevent any SR SSC from satisfying all the critical safety functions. Further, the NRC requires that some industrial components, such as turbine building, and steam and feed water piping, be seismically qualified (Law, 2016).

In 1986, the NRC introduced the *important to safety*[70] classification for SSCs that provide "defense-in-depth" or mitigate risk significance for beyond design bases events (Thompson, 1985). NRC Rules require a limited QA approach for these SSCs, commensurate with the safety significance of the application[71]. For example, the required supplemental power source[72] used if all power fails, was classified as an "important to safety" component.

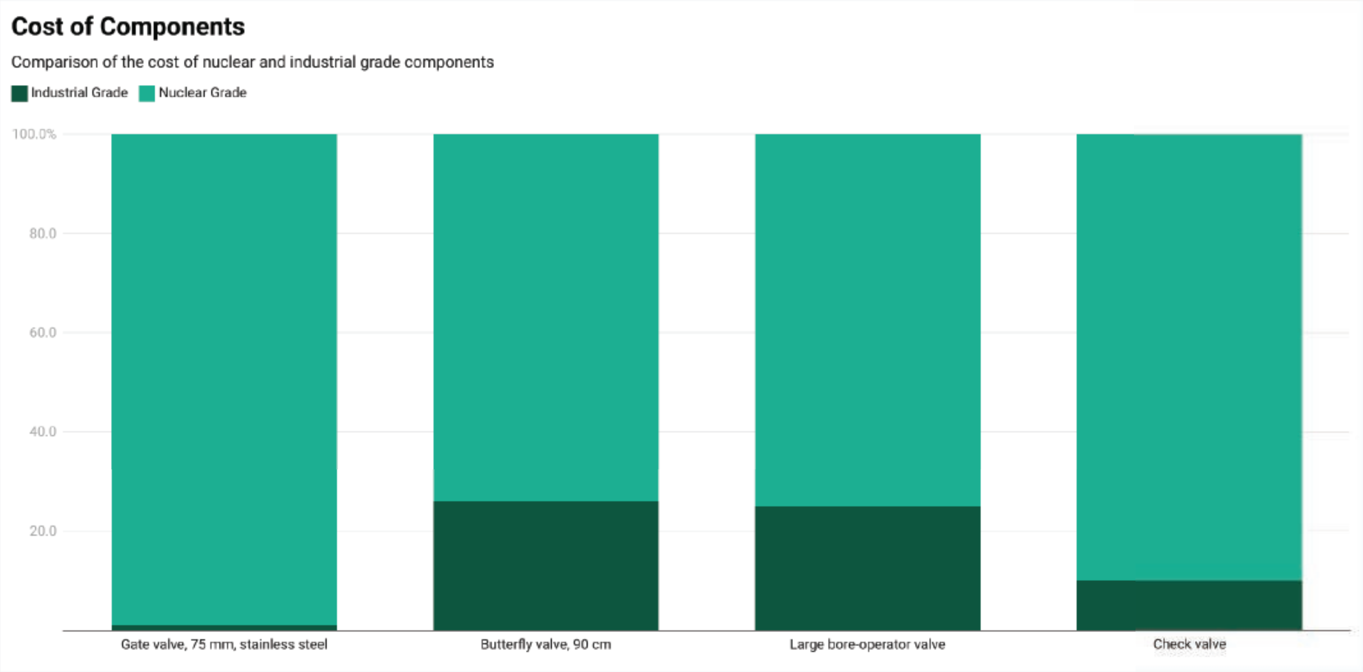
The final and most stringent legal category is *safety related (SR)* SSC's. SR SSCs are identified during the facility licensing process. Only SR SSCs may be credited in facility safety analyses to demonstrate mitigation of events which could result in either core damage or unacceptable off-site radiological consequences. These safety analyses rely on SR SSCs to ensure: 1) The integrity of the reactor coolant pressure boundary; 2) The capability to shut down the reactor and maintain it in a safe condition; and 3) the capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures exceeding regulatory limits[73].

The NRC requires these SSCs to perform the safety functions specified in safety analyses, with and without off-site power, and during and after certain environmental events. For example, a SR valve must be qualified to remain fully functional following the maximum postulated earthquake, storm, or flood, and the environmental conditions[74] resulting from the worst-case reactor accidents.

70 ATWS Rule, 10 CFR 50.62, Quality Assurance Guidance.
71 Provides reasonable assurance that the facility can be operated without undue risk to the health and safety of the public.
72 Required per 10 CFR 50 10 CFR 50.63(a)(1), "Loss of all alternating current power" (Nuclear Regulatory Commission, 2021d).
73 Comparable to those referred to in § 50.34(a)(1), § 50.67(b)(2), or § 100.11 of this chapter, as applicable.
74 Environmental conditions can include very high radiation exposure, high temperatures, and submergence.

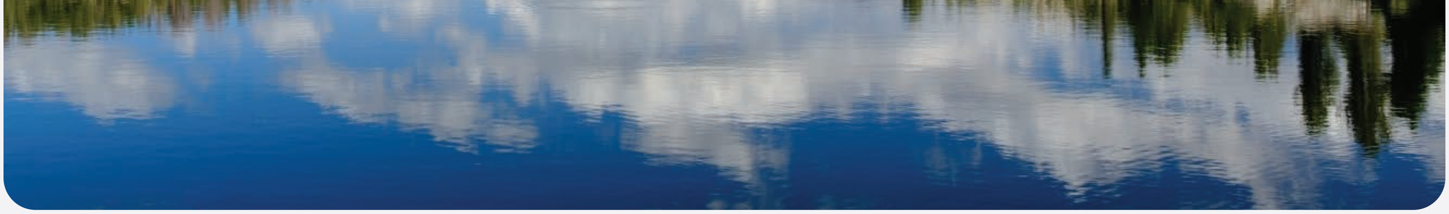
Safety related components are significantly more expensive to manufacture than comparable components classified as industrial grade. The overall production cost of some SR components is disaggregated into material costs and legal costs in Figure 19. For the valves evaluated, between 80% and 99% of the production costs come from meeting NRC safety requirements. Safety related components compose most of the capital cost in the nuclear power plant, making these legal costs significant to nuclear power plant profitability.

Figure 19:
Comparison of the Cost of Nuclear and Industrial Grade Components[75]



A key NRC requirement contributing to this cost is in Part 50 of Title 10 of the Code of Federal Regulations (CFR) (Nuclear Regulatory Commission, 2021a). SR SSCs must be manufactured with the QA requirements set forth in this rule, and the codes specified as a condition of facility licenses (Nuclear Regulatory Commission, 2023a). Other mandatory codes and standards apply to SR electrical, pressure retaining systems, control, mechanical, ventilation, emergency core cooling systems (ECCSs), and structures.

75 Original data source for Figure 19 comes from models provided by (O'Regan, 2012).



Quality assurance requirements of the NRC[76] must be met when acquiring SR nuclear components. Beginning in 1978, ASME began certifying the quality assurance programs of nuclear suppliers as compliant with NRC rules[77]. One form of the ASME certifications are N-stamps which apply to pressure retaining components that have additional quality assurance standard requirements[78, 79] (See Appendix (I)). A nuclear operator can add N-stamp supplier to their approved vendor list, followed by an audit. The N-stamp component from an ASME certified supplier must meet quality assurance requirements of the SR component minimizing audit costs. Alternatively, an NRC licensee may perform independent QA audits of a SR supplier. These audits are resource intensive and must be led by a certified lead auditor. Professional associations have developed to minimize redundant audit costs including the Nuclear Industry Assessment Corporation and the Nuclear Procurement[80].

Receiving ASME certification is expensive, requiring suppliers to develop and implement multiple complex administrative and management systems, well beyond typically required for industrial manufacturing (American Society of Mechanical Engineers, 1989).

Ron Pitts, the former vice president of Flour Corporation's nuclear component branch, stated:

> "N stamp certification is not an inexpensive undertaking. For previous N stamp holders that still have procedures in place and that are ISO 9000 qualified, certification costs may be in the $1 million range. For companies seeking their first N-stamp, the costs could be many times more. The real expense isn't so much in the certification process itself, but for the costs associated with establishing an effective quality assurance and quality control program to support N stamp requirements" (Clarion Energy Content Directors, 2009).

The high upfront investment in an ASME N-stamp allows manufacturers to sell their component for a higher price over the three-year term. A company will find it worth investing in the N-stamps if they continue to produce nuclear components for a long enough period to overcome these setup costs, otherwise an independent audit is more economically efficient.

76 Found in Part 50, Appendix B.
77 This uses the NQA-1 guidelines which were developed by the ASME and endorsed by the NRC as meeting Part 50 Appendix B requirements.
78 Section III of the ASME Boiler and Pressure Vessel (BPV) Code.
79 First mandated by the NRC in 1963, ASME BPVC, Section III, "Rules for Constructions of Nuclear Facility Components-Subsection NCA-General Requirements for Division 1 and Division 2."
80 See (Nuclear Industry Assessment Corporation, 2024; Nuclear Procurement Issues Corporation, n.d.).

A final option available to nuclear power plant owners purchasing SR components, is to purchase components that are not ASME certified and then perform a *commercial-grade dedication.* The dedication process requires the licensee to demonstrate that the component meets all the "form, fit, function, and qualifications" of the equivalent SR SSC. Commercial part dedications can be a complex process. As some of the equivalent SR attributes for a component may be proprietary and unknown to the licensee. Many nuclear safety issues and NRC violations have been issued because a licensee failed to understand the complexity of a particular component that was improperly dedicated under this process.

These compliance costs create a financial barrier for Wyoming firms entering the nuclear component market, but also provide benefits to the State. Ensuring the safe operation of power plants will directly benefit citizens of Wyoming as nuclear produced electricity is added to the State's generation portfolio. From an economic lens, the added manufacturing costs are balanced against potential safety gains.

A few economic principles are relevant for reducing these legal costs as optimal regulations provide flexibility in the methods used to reduce risk. Legally assigned technological standards are less efficient than requiring safety standards without specifying how the safety goals are met (Lange & Bellas, 2005). The component approval process does allow firms to use a range of components, but the process creates a de facto cost penalty for using innovative designs or advanced manufacturing methods. Consequently, some technologies are financially favored over others in the design process. The NRC is working on updates for AMT methods, to account for industry changes (Nuclear Regulatory Commission, 2021b). Promoting responsive policy change can mitigate the innovation discouraging effects of this framework and will reduce the legal barriers for nuclear component manufacturing.

Economically optimal policies capture the full public cost of private action, while allowing companies to balance those costs (Coase, 2013; Hardin, 1968; Pigou, 1924). Policies, such as mandatory disaster bonds, could lower the regulatory burdens of entering the nuclear manufacturing market without reducing safety outcomes (Louaas & Picard, 2022). In such a system, no specific QA requirements would be required by law, but company profits are increased by providing optimal QA levels. Lowering disaster risk increases the value of the disaster bonds, whether done via a QA program or other means. This would no longer disadvantage AMT and innovative designs. Such a radical change in the legal structure may be infeasible in the U.S. but policy can be moved in that direction. Wyoming can promote adjustments to QA guidelines that reduce costs for component manufacturing where the regulatory costs outweigh the safety benefits. This requires extensive dialogue with nuclear experts to identify ways to streamline regulation without compromising significant safety. The benefits of conservative safety standards are especially relevant to scenarios where disasters are rare but highly costly (Nordhaus, 2012). Considerations should be made that factor in the importance of risk avoidance, and the economic gains of providing more options to manage the risk of component failure.

Summary

These regulatory standards are complex and add significant cost to nuclear component manufacturing. There is variation in the imposed restriction between components produced. For small non-safety components, the score falls into the *minor advantage* category. Other small components for first-of-a-kind designs disproportionately face regulatory hurdles. In totality small component legal challenges fall into the *minor obstacle* scoring range. Some components can be developed in Wyoming without modification to existing rules, but streamlining the compliance cost of components and advanced manufacturing will improve the prospects of new manufacturers.

The largest nuclear components cannot currently be produced in the U.S. Innovation is needed to develop economically viable designs employing modular construction for this manufacturing sector to be cost competitive with existing foreign manufacturing. However, innovation comes with legal uncertainty, and added costs. The regulatory process can be streamlined to promote continued cost reductions in large components produced in the U.S. For this reason, the legal score for large components is in the *moderate obstacle* range.

BENEFITS AND COSTS

The benefits and costs of developing a nuclear component manufacturing industry in Wyoming were evaluated using micro-economic models. The manufacturing industry is dependent on the expansion path of nuclear power. In the upper range of nuclear growth scenarios, Wyoming is expected to acquire between 800 and 14,100 job-years, and between $3.5 and $65.5 million in State and local revenue by 2050[81]. Due to a stagnation in nuclear power plant construction in the U.S., the lower range of outcomes is that the industry will not expand, and no jobs or revenue will be acquired.

4.1 GENERAL BENEFITS

If the nuclear components manufacturing sector develops in Wyoming, some indirect benefits would be accrued. These include spillovers benefits for the State economy, and the long-term development of an integrated nuclear industry.

Promoting nuclear manufacturing will encourage cost reduction in a developing energy sector and Wyoming firms will gain experience with advanced nuclear technologies. Emerging industries are able to reduce production costs through experience (Arrow, 1962). While the source of this effect is debated, there are clear cost gains for emerging energy technologies through experience (Lovering et al., 2021; Pan & Köhler, 2007). For the nuclear sector, this growth in Wyoming will promote long term cost reductions potentially making advanced nuclear cost competitive.

[81] Including indirect and induced jobs and tax revenue.

In the process, companies in the State will gain unique skills not easily replicated. This would allow Wyoming firms to be more adaptive during periods of growth in nuclear demand than states without an existing nuclear component manufacturing sector. A second benefit is the promotion of other Wyoming industries. As there exist economic advantages to colocation of related sectors. These include knowledge spillover, easier communications, and economies of scales along shared inputs. By developing the specialized components needed for nuclear reactors in the State, future Wyoming nuclear power plants and SMR's would gain an advantage from the ability to communicate with the supplier directly.

One way to model the knowledge spillover and industry location is through a gravitational model (Haynes & Fotheringham, 1984). As industry specific human capital and inputs/outputs develop, there is a stronger pull towards that location. Promoting nuclear component manufacturing in Wyoming can contribute to the State becoming a node for nuclear related firms.

4.2 GENERAL COSTS

No social costs of developing a Wyoming nuclear component manufacturing sector were identified. While other sectors of the nuclear supply chain contain distinctive safety or pollution challenges, such as radiation protection and spent fuel storage, there are no such costs to manufacturing. Wyoming already maintains a substantial manufacturing sector and many of the parts related to nuclear power plants are produced using similar techniques as nuclear components. An expansion of the nuclear manufacturing industry therefore would not create new forms of unique costs.

The preceding economic impact model includes an analysis of environmental outcomes from nuclear component manufacturing. Even under the largest forecasted expansion of components manufacturing, the pollutant increases are marginal (see Appendix L). The most notable impacts are an increase in non-toxic waste by one ton per year and an increase in water withdrawals of 1,800 Acre-feet per year[82].

4.3 ECONOMIC IMPACTS

Outcomes in employment and tax revenue from a future nuclear component manufacturing sector in Wyoming were estimated. This was done through a combination of micro economic models of the Wyoming economy and forecasts of future nuclear power plant demand.

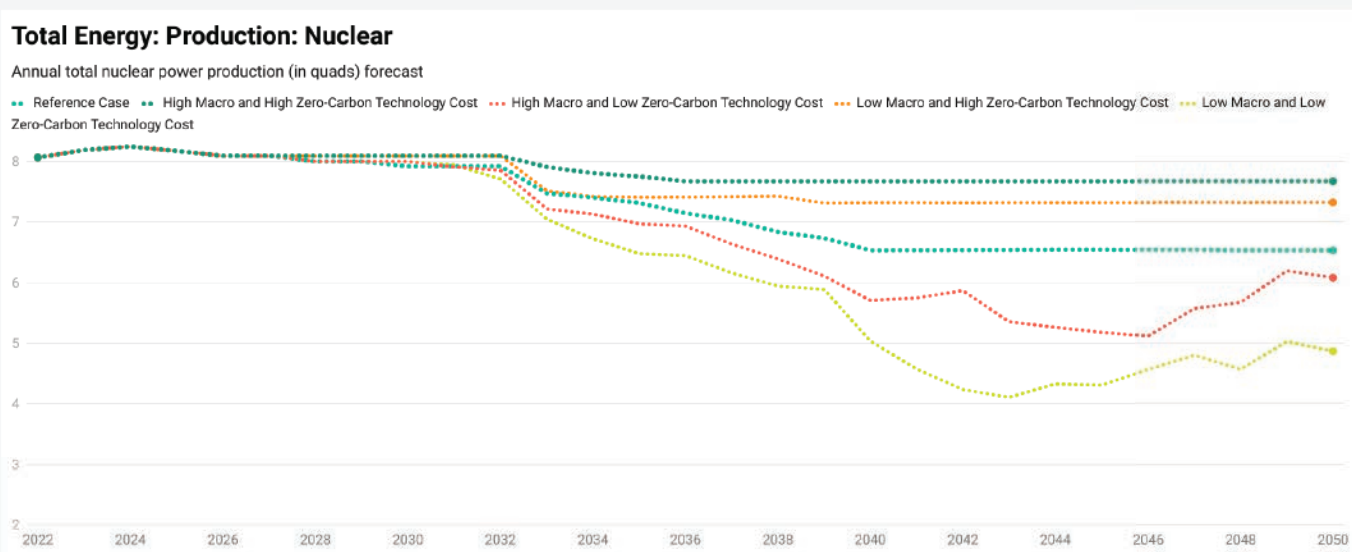
[82] Total impact is divided by 26 years since the changes are forecasted to 2050.

The benefits and costs of the nuclear component sector in Wyoming were evaluated using an input-output model (Leontief, 1986). In these models, the inputs of one sector are treated as the outputs of another and the system of equations is balanced with available data. The model applied comes from IMPLAN, which includes sector level data unique to Wyoming allowing for the economic impacts to be tailored to the unique economic linkages in the State[79].

The outcomes of the input-output model are generated under four cases of nuclear power growth in the U.S. Since the output of the nuclear components industry is directly tied to the number of newly developed power plants, the expectation of future nuclear power generation informs the response of manufacturing firms.

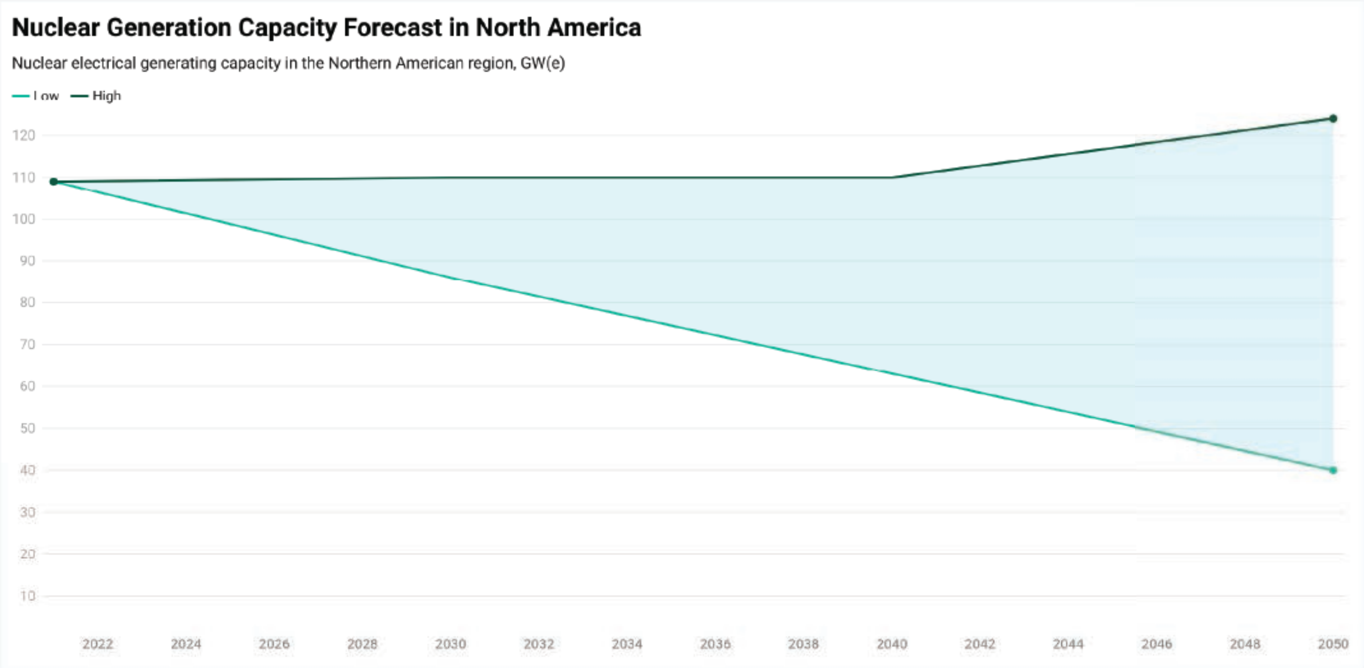
Three reports were used to create reference cases for changes in the quantity of nuclear components demanded. The EIA's 2023 Annual Outlook Report uses cost models and policy inputs to project future energy production in the U.S. (Energy Information Administration, 2023b). Similarly, the International Atomic Energy Agency (IAEA) provides an economic forecast of global nuclear power production (International Atomic Energy Agency, 2022a). This is supplemented with the Department of Energy's report on SMR industrialization (Kozeracki et al., 2023). A subset of economic scenarios from the EIA forecast are presented in Figure 20. The future nuclear capacity as predicted by the IAEA is provided in Figure 21.

Figure 20:
EIA Nuclear Power Forecast[84]



83 More information on the IMPLAN modeling process is available at IMPLAN.com.
84 Data source used to create this figure comes from (Energy Information Administration, 2023c).

Figure 21:
Nuclear Generation Capacity Forecast in North America[85]



Both the EIA and IAEA reports provide a range of outcomes under different economic scenarios up to 2050. In both models, the base case predicts that nuclear power output in the U.S. declines, as some older nuclear power plants retire[86]. Multiple factors contribute to this forecasted outcome, including expected reductions in renewable energy prices (a substitute to nuclear) and an already large fleet of nuclear power. The IAEA report predicts an overall increase in global nuclear power, especially in Asia, but a net decrease in North America. From these forecasts, it is assumed that in the "low" reference cases the nuclear components industry will remain static, and no additional components will be manufactured in Wyoming.

However, even as nuclear electricity output is predicted to fall, new nuclear power plants can be added to replace a portion of the retired capacity. Figure 22 uses the EIA Annual Outlook Report (AOR) data set to demonstrate how nuclear power plant additions could change across time (Energy Information Administration, 2023c). The technological cost of nuclear power production is the main driver of the forecasted nuclear additions. Each EIA model without low technological costs is identical to the reference case. Based on this fact three scenarios are compared to the reference case, all assuming low nuclear technology costs in the future. The models compare expectations of nuclear additions under low, average, and high U.S. macro-economic growth.

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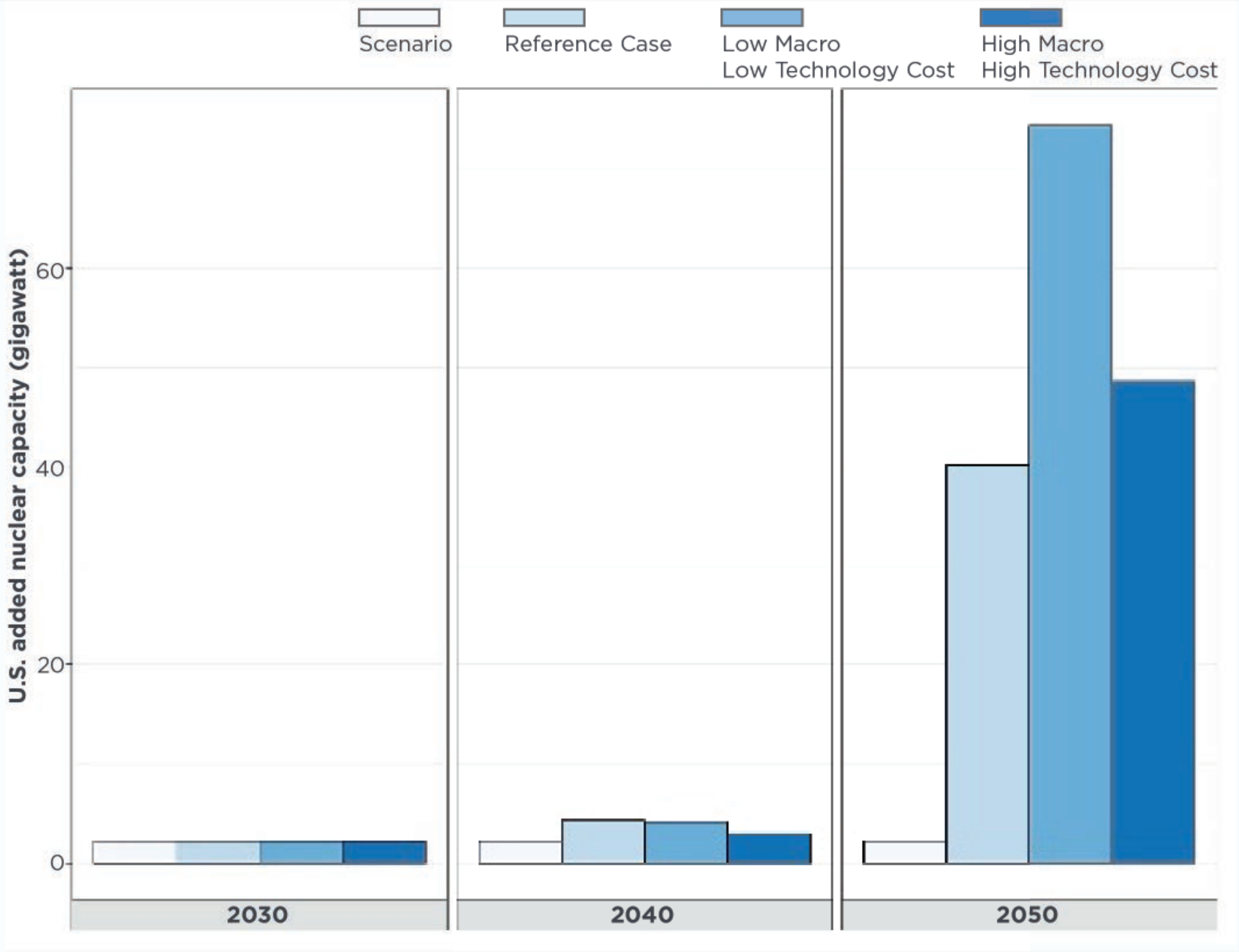
85 Data source from (International Atomic Energy Agency, 2022a).

86 High renewable energy costs improve the prospect of nuclear energy because renewables are a substitute low carbon energy source. For example, if wind power becomes cheaper the opportunity costs of nuclear increase. More relative profit can be made by investing money in other technologies, this is true even if the efficiency of nuclear improves from a engineering standpoint. High economic growth shifts demand so that more energy is required, and a base load like nuclear has relative higher value that intermittent energy sources such as wind and solar.

Figure 22:
Added U.S. Nuclear Capacity Under EIA Forecasts[87]



Interestingly U.S. nuclear power additions do not strictly increase along with macro-economic growth. The most nuclear additions occur when U.S. experiences economic average growth rates, avoiding either macroeconomic extreme. These unintuitive results can be supported by economic principles. During periods of high economic growth interest rates increase[88]. Nuclear produced electricity is the most capital-intensive source of power in the U.S. (Energy Information Administration, 2022a). This means that higher interest rates dampen the growth of nuclear power more significantly than alternative low capital electricity sources such as natural gas.

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[87] Additions are not included in the main EIA report. Data is collected using the EIA open data API (Energy Information Administration, 2023c).

[88] This can occur either through private banks, or through federal reserve policy target to minimize inflation.

There are several nuclear facilities being developed in the U.S., such as the Kemmerer TerraPower project which are essential for each outcome in Figure 22. Such facilities create a source of demand for nuclear components directly and are the only expected additions under the reference case. The knowledge gained through these projects reduces the levelized cost of nuclear power, pushing the U.S. closer to a low nuclear technology cost scenario, necessary for expanded growth by 2050. If these developments reduce nuclear power costs significantly, and there is normal U.S. economic growth the high nuclear demand scenario will be reached. Based on these forecasts it is assumed that 2.23 Gigawatt of capacity is added to the U.S. electricity grid in the *middle* demand scenario, and 74.4 Gigawatts in the *high* demand scenario.

Accounting for the demand of new nuclear power plants for research purposes and the resulting cost reductions, a third reference case was developed. In this case study, it was assumed that five SMR reactors are created by 2050 which meets the minimum DOE threshold for commercialization (Kozeracki et al., 2023). It is also assumed that one new advanced reactor will be constructed to replace retiring coal power plants. While outside of the median forecasts of nuclear demand neither scenario is implausible. Continued research of SMRs provides an avenue to create demand for nuclear components even while the technology is subeconomic. One AP1000 reactors became operational in 2023. While no new commercial scale reactors are planned in the U.S., retiring coal plants along with a shift in production costs of nuclear power plants may induce at least one traditional reactor installation in the U.S. by 2050. This reference case is the "*middle-high*" demand scenario.

The upper bounds reference case combines the AOE predictions under ideal conditions, with the EIA estimate of SMR investment needed for commercial viability. It is estimated that no more than ten SMR units are required to reach commercially viable growth in the sector (Kozeracki et al., 2023). This is taken as the expected number of SMR additions, by 2050 in the high demand scenario. The high end AOE reference case estimates 74.4 GW of capacity will be constructed by 2050[89]. Deducting the capacity of the ten added SMR's leaves a gap of 70 GW to be filled by advanced nuclear power plants[90]. Filling this gap requires 32 benchmark advanced nuclear reactors to be constructed[91].

The expected quantity of nuclear power plants constructed by 2050 under each are summarized in Table 11.

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[89] 22 GW is higher the net predicted nuclear power increase in the model because some nuclear power plants are assumed to be retired. The 22 GW is the total new construction added, including the replacement in capacity.

[90] Benchmark uses a AP1000 reactor, assumptions derived from (Energy Information Administration, 2020).

[91] 32.3 power plants are estimated for the model but whole numbers are reports in text since fractional power plants cannot be constructed. For model estimates fractional power plants are reasonable since the capacity of nuclear power plants are not constant.

Table 11:
Nuclear Power Plant Demand Reference Cases

Demand Scenarios	Low	Middle	Mid-High	High
Advanced Nuclear	0	0	1	32[88]
Small Modular	0	4	5	10

The number of new nuclear power plants is the input to nuclear power production, but the output of the nuclear component manufacturing. This fact is used to forecast the economic outputs of the nuclear component industry under each scenario. The cost of the mechanical components of nuclear power plants are estimated to be $1.80 billion for a SMR power plant complex, and $5.7 billion for advanced reactors (Energy Information Administration, 2020). Electrical components from nuclear power plants are estimated to cost $0.32 billion for SMR designs and $0.96 billion for advanced reactors (Energy Information Administration, 2020)[92].

The model treats this cost as a revenue expansion of the nuclear component sector under each growth prospective. It is assumed that reactor vessels and boilers for commercial nuclear power plants are constructed outside of the U.S., since there are no manufacturing facilities large enough to produce AP1000 reactors domestically and the identified barriers for large component manufacturing[93]. It is also assumed that 76% of the mechanical cost can be attributed to these large components based on historic plant design (Rothwell, 2018)[94]. To achieve the *high* demand scenario capital costs are reduced by 40% (Energy Information Administration, 2023a). Under this scenario the lower costs increase the quantity of new nuclear power plants from one to 32 but each power plant provides 40% less income for component manufacturing. SMR designs are assumed to be entirely constructed in the U.S. The total nuclear component output increase in billions of dollars is provided in Table 12[95].

In the middle demand scenario, the manufacturing industry will increase output by $8.4 billion with an upper bound of $64.2 billion in the high demand benchmark. This total industry outgrowth is provided to IMPLAN to model U.S. level economic impacts.

[92] 32.28 PowerPlants= (74,400 Mw - 10 SMRs * 480 Mw) / (2,156 Mw/PowerPlant).
[93] All values inflation adjusted to 2023.
[94] See Economic Barriers section for an explanation of the economies of scale that lead to the assumption that large components will be produced overseas.
[95] Values are inflation adjusted to January 2023 levels.

Table 12:
Production Expansion of Nuclear Component Manufacturing

		Demand Scenarios U.S. Manufacturing Output (Bill. USD)			
Parts	**Type**	**Low**	**Middle**	**Mid-High**	**High**
Mechanical Components	Adv.	0	0	1.4	26.3
	SMR	0	7.1	8.9	17.8
Electrical Components	Adv.	0	0	1.0	18.6
	SMR	0	1.3	1.6	1.9
Total		0	8.4	12.8	64.6

To apply this national forecast to Wyoming, it is assumed that in these growth paths, Wyoming will be able to acquire capital investment at a rate proportional to existing manufacturing. Wyoming is found to have an advantage for attracting manufacturing facilities in the tax analysis and location analysis assuming continued growth of nuclear power in the State. The State produces 1.6% of all manufacturing in the U.S., while having only 0.17% of the country's population (U.S. Bureau of Economic Analysis, 2005; US Census Bureau, 2023). This disproportionate level of production is attributable to State characteristics, such as government policy, electrical grid consistency, a developed energy sector, and location specific factors. Yet no ASME N-stamp holders currently operate in Wyoming.

This disparity can be explained through path dependent growth. An institution's development is often path dependent, decisions made under bygone economic conditions locking in sub-optimal choices as the economy shifts (David, 1985; Libecap, 2009). The location and level of investment in nuclear component manufacturing was made as the sector expanded in the 1970s-1980s. At this point, nuclear power plants were built near the population centers on the East Coast. Also, the Wyoming tax credit for manufacturing capital was decades away and modular designs allowing easy transportation of parts were less advanced. Location decisions made under these conditions are restricted, until there is enough growth to build new facilities. A sample of twenty component firms were reviewed in detail to identify the first operating date and only 20% were constructed after 1990 with 5% after 2000. Under the earlier economic conditions, it makes sense that existing firms locate in other states, but this is not likely to remain the case. Under new economic conditions, Wyoming has a comparative advantage in manufacturing and nuclear manufacturing is expected to converge with the States overall manufacturing level. From this assumption, Wyoming is expected to capture 2% of the sector growth of Table 12.

The model separates the mechanical costs from the electrical equipment costs and applies industry linkages calibrated to Wyoming's economy. The mechanical costs of nuclear power plants are treated as an output shock to power boil and heat exchanger manufacturing. Electrical components costs are modeled as output shocks to electricity and signal testing instruments. The shock in these two manufacturing industries is then propagated across each economic sector. These interconnected economic shocks range from direct demand for raw materials to produce the parts, to more indirect effects such increased purchases at restaurants. The net effect of all of these economic linkages are used to estimate the total number of jobs and tax revenue associated with the establishment of nuclear component manufacturing in Wyoming.

Table 13:
Nuclear Power Demand

Nuclear Power Demand Scenario	Low	Middle	Mid-High	High
Jobs (Person-Years)	0	800	1,600	14,100
Tax Revenue[96] (Mill. USD)	0	$3.5	$7.1	$61.5
Benefits	None	Industry colocation		
Costs	No major costs			

The model output for the *middle* scenario is a creation of 800 person-years' worth of labor, and $3.5 million in State and local tax revenue. The *middle-high* outcome is the creation of 1,600 job-hours with $7.1 million in tax revenue. Finally, the *high* demand scenario would induce 14,100 person-years of employment, with $61.5 million in State and local tax revenue. Based on the development timeline in Figure 22 most of these benefits would accrue around 2050, with few economic impacts occurring in the intervening period.

The relative importance of SMR construction to the economic outcomes' changes along the scenarios. In the middle case all revenue, and job creation are attributable to SMR's, in the mid-high case, 61.3% of benefits are accountable to SMR's, but in the high demand scenario advanced reactors provide the highest economic benefits with 86.7% of all generated jobs and tax income. 63.4% of employment gains come directly from the manufacturing industry, with the remainder coming through indirect spillover effects. The largest indirect output changes are linked to real estate, warehousing, and storage industries.

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[96] Total State and County revenue accrued by 2050, including both direct and induced effects.

CONCLUSIONS

The study evaluated the opportunities and barriers for a new nuclear component manufacturing industry in Wyoming. Small components are found to face no major barriers to economic development in the State. Continued expansion of nuclear power in Wyoming, and promotion of streamlined legal process will minimize the identified obstacles. More hurdles are identified for large component manufacturers, which require significant capital investments. Three factors were found to promote small component manufacturing in the State, and three factors were found to be minor obstacles.

Factors Supporting Development

1. Existing manufacturing firms in Wyoming can take advantage of future growth in nuclear demand.
2. Tax exemptions for manufacturing in Wyoming provide an incentive to locate in the State.
3. Current trends in technological adoption within the manufacturing sector will continue to improve manufacturing quality and costs.

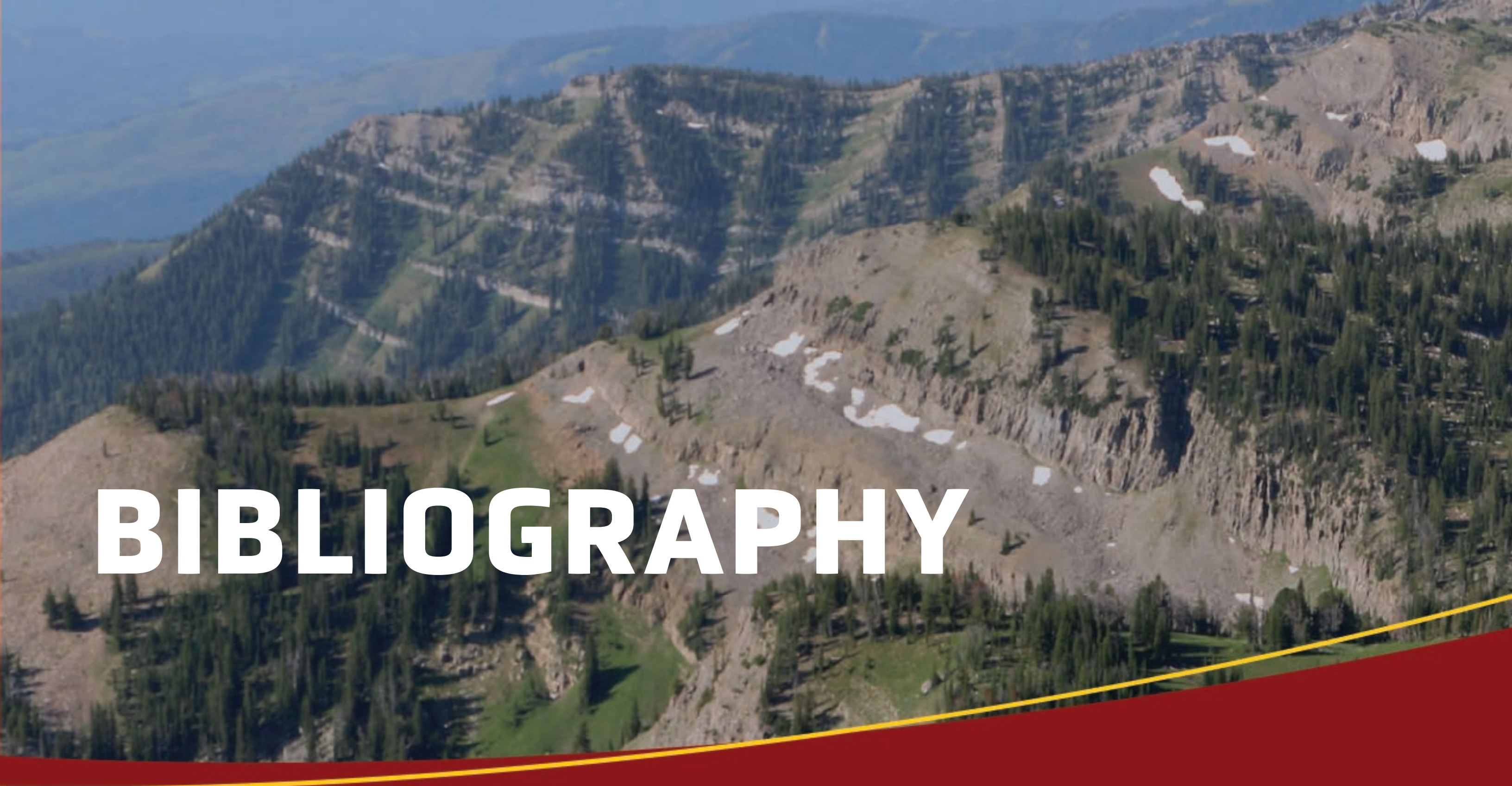
Barriers to Development

1. Manufacturing trends show a shift from domestic to overseas production.
2. Cold weather, and no (current) nuclear power production are minor disincentives to locate in Wyoming.
3. Significant regulatory compliance costs are associated with nuclear component manufacturing.

The State is well positioned to expand production in the long term as nuclear power production increases. However, economic forecasts of nuclear power production suggest there will be little growth in the U.S., consequently affecting the prospects of Wyoming industry. The total benefits to the State include:

Benefits of Wyoming Component Manufacturing

1. 800-14,100 person-years of employment.
2. $3.5-$61.5 million of tax revenue.
3. Promotion of existing manufacturing.
4. Development as a regional nuclear energy producer.
5. Contribute to cost reductions of nuclear power.



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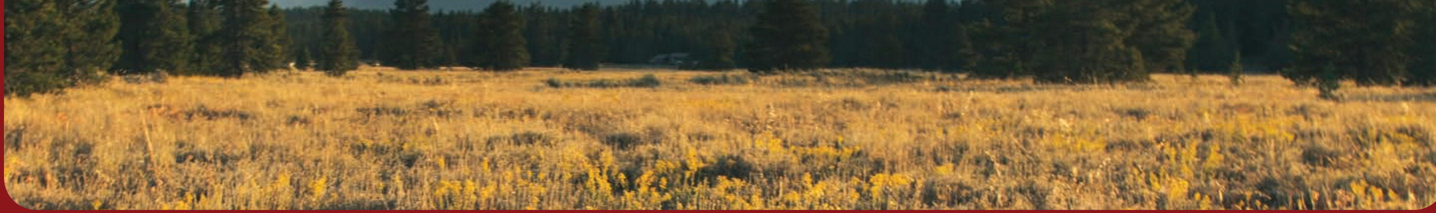

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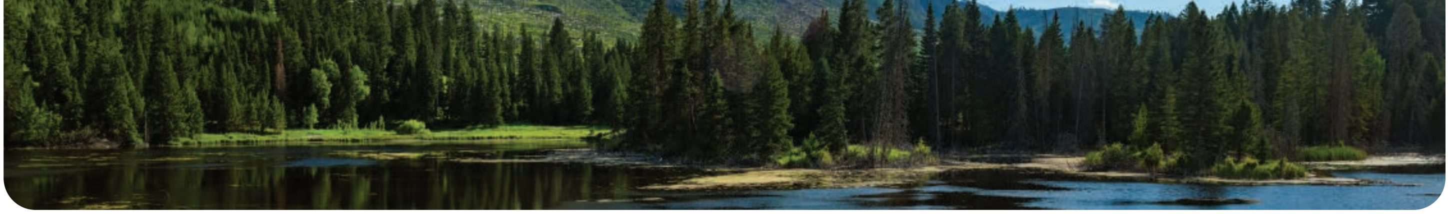
APPENDIXES

APPENDIX (A) DATA COLLECTION PROCESS

This appendix provides a summary of the data collected and explains the collection process. To create a structured panel data multiple data sets were collected and aggregated to the state year level. The primary data set comes from ASME (American Society of Mechanical Engineers, n.d.). The provided data includes the company name, address, type of certificate issued, the date of first issuance, and the termination date (if applicable).

Weather data is provided by NOAA, through an ftp server (National Oceanic and Atmospheric Administration, 2023b). The csv files include a range of data about natural disaster events but are parsed to extract the relevant information. The final values calculated include: the event type, the number of deaths and value of damage from a weather event, the county or state the event occurred in and the start/end date of the event. The R code applied parses the CZIPS codes used by NOAA to standard FIPS codes, allowing the state to be identified. The units are parsed to make the values consistent across groups. For example, the csv files may report 10k in damaged property which is $10,000 while 10M is $10,000,000. All dollar values were inflation adjusted using the CPI (U.S. Bureau of Labor Statistics, 2023c). A natural disaster is always assigned to the year that the event began. This can cause issues if an event starts in December and continues into January. However, this is not a common occurrence for hurricanes and tropical events which contribute most to overall deaths. Deaths were summed by each year and state for all events, and then averaged to form the state fixed constant.



In a separate NOAA data set, temperature data is collected (National Oceanic and Atmospheric Administration, 2023a). This web page allows the user to select the state, and data type resulting in a link to a csv download page with the desired data. The pattern of the csv URLs for each state and data type (heating degree days, temperature) was identified, and R code was used to scrape each file in a loop across all 48 contiguous states. These files uniquely identify the state, year and data type included. The data collected in this manner includes heating degree days, cooling degree days, and average temperature. Values since 1980 were averaged to provide a time constant estimate for each state.

Data pertaining to the operation of power plants was gathered from the EIA (Energy Information Administration, 2023d). For each reactor, the state, date of operation, date of closure, energy type, and nameplate capacity were collected. The total nameplate value for each energy type was summed by state and year. A list of states with a shared boarder was created, to calculate the nameplate capacity of all adjoining states in each year. The final regression treats the name plate capacity as being part of the state fixed effect. Even though there is time variation these changes are moderate and are known to all users well before the change occurs. This data is summarized in Table 14.

Table 14:
Nameplate Capacity State Summary Statistics[97]

Statistic:	N	Mean	St. Dev.	Min	Max
Nuclear	48	2,142	2,754	0	12,415
Coal	48	5,710	5,352	0	20,742
Hydro Electric	48	2,090	3,783	0	21,433
Natural Gas	48	8,252	10,882	0	63,586
Petroleum	48	905	1,374	3	7,160
Solar	48	217	536	0	3,468
Other Sources	48	390	687	1	4,537
Total	48	20,482	18,063	632	101,618

[97] Nameplate capacity is reported in MW

State size was provided by the U.S Census bureau (US Census Bureau, 2010). States with a shoreline were manually identified, this is used as a dummy variable to capture the effect of maritime trade.

Macro-economic data is provided from FRED, and R packages are used to aggregate data sets to the year level (R Core Team, 2023). Data collected includes unemployment rates, manufacturing employment, state population, and the amount of corporate income taxes collected (U.S. Bureau of Economic Analysis, 2023; U.S. Bureau of Labor Statistics, 2023a, 2023b; World Bank, 2023). The code to gather and aggregate the data sets for each 48 contiguous states is available upon request. A summary of this data is provided in Table 15.

Table 15:
Macro Economic Summary Statistics

Statistic	N	Mean	St. Dev.	Min	Max
Population	1,584	6,100.0	6,596.9	453.4	39,501.7
Manufacturing Employment	1,551	300.6	304.7	8.7	1,971.3
Unemployment	1,584	5.4	1.9	2.1	13.7
Corporate Taxes (billion USD)	1,539	0.8	1.5	0.0	26.1

A final data set comes from the IAEA report on nuclear reactors (International Atomic Energy Agency, 2021). This data provides information about all reactors planned or operational in the world. The relevant data to this analysis includes the construction start date, the suppling company of each reactor, and the location of the final power plant, the nameplate capacity of the reactor, and the retirement date of a reactor. The PDF tables are processed to extract this data, which is used to plot the additions and retirements of reactors in Figure 1. It is also used to link the location of reactor production to the destination indicating that there is a spatial component to this choice.

ASME data processing steps

The ASME data set is not easily accessible for analysis and requires a multi-step procedure to collect. ASME provides a searching tool to find ASME accredited companies. All available 29,115 ASME certificate pdfs are downloaded over a loop using python, the data is then merged, transformed to text, and processed in bash, final cleanup and aggregation is completed in R. It should be noted that advertising ASME certification is an advantage for companies since the accreditation raises the value of their product. For this reason, the data set is assumed to be complete.

When accessing the ASME search tool, the query results provide access to a list of certificates matching the conditions. Certificates can be selected from this list which provides a pdf with detailed information about the certificate holder. A typical certificate pdf is provided in Figure 22.

Figure 23:
Example ASME Certificate PDF

CA Connect

ASME
SETTING THE STANDARD

CERTIFICATE HOLDER DETAILS

Certificate Type	N
Certificate Number	N-1076
Certificate Status	Active
Company Name	Valcor Engineering Corporation
Abbreviation	VALCOR ENGRG CORP.
Company Address	2 Lawrence Road Springfield New Jersey USA 07081
Scope	Construction of Class 1, 2, & 3 vessels, valves and piping systems at the above location only
Original Authorized Date	04/27/1990
Authorized Date	05/06/2023
Expiration Date	05/06/2026

These files appear to be generated on the fly, and there is no ftp server publicly accessible. Selecting multiple certificates allows multiple records to be accessed in the PDF, but the webpage display limits the number that can be downloaded at once. There appears to be no straightforward ways to manipulate the html to automatically download the files so a more mechanical method was used.

Software was used to automate mouse and keyboard movements, in a virtual machine (Mairo, 2019/2023). The python script generated by this program automates checking each certificate on a page, printing the combined pdf to file, and then changing the page so that new records are displayed. The search used had no parameters so that the ASME search tool included each certificate in the data set. The python script started at the end of the data set, and worked backwards as this was more consistent than working front to back.

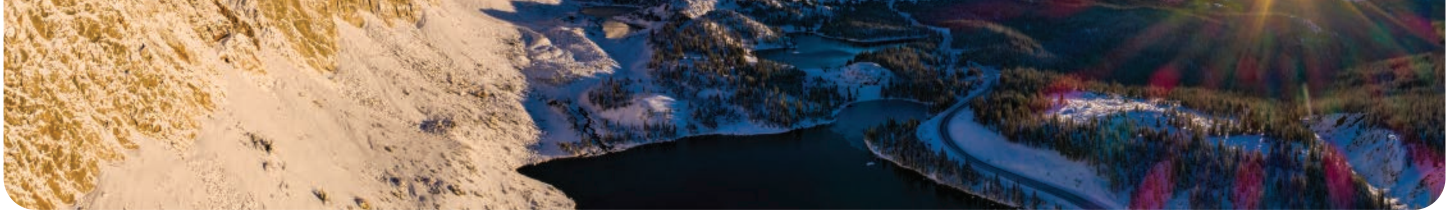
There is room for error in this process, as exceedingly long names can cause the checkboxes to change location. This was alleviated by working with the page at minimum size. While there is no way to verify that every record was acquired the final data set matches perfectly the expectation of 12 records per page with 1,941 pages of data, as is present in the main ASME query. If data is missing it will only be a few records and these missing records are unlikely to be selected in a non-random manner. At worst, the selection process biases towards companies with short names, but this is not expected to be significant to the results.

Once each Pdf was collected, they were merged, and then converted to text using the pdftotext Unix program (Astals Cid, 2023). The resulting text file was then processed to identify the starting line of each certificate record, and then each data field of the record was combine into a single line (Free Software Foundation, 2022). The bash script for this process is available upon request. The resulting file is a tilde separate file, with each entry having the data name, followed by the data. For example, the data in Figure 22 would look like:

Certificate Type~N~Certificate Number~N-1076~Certifcate Status~Active … Expiration Date~05/06.2026

This data was loaded in the R program using the tidy software (Wikham et al., 2023), and processed to the final form. The code separates the column name from the data, and merges all records into a single data file, which is exported as a csv. Both the file and R code are available upon request.

Some records of N type certificates have multiple entries. These are cases where extra certifications were acquired for different aspects of the same project. The id number of the primary certificate is the header of the other related certificates which appends a number (-1,-2,..) to the certificate. These are parsed out as separate data points and assigned their own certification number.



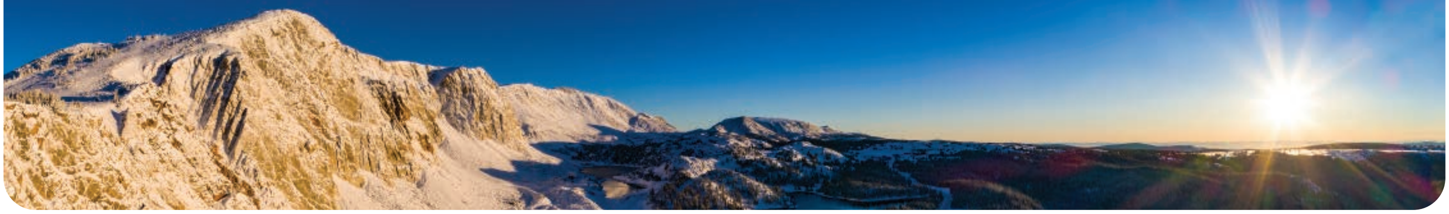
Additional cleanup was completed on this data set. The company addresses were parsed to extract the country and state of origin. The zip code was also obtained, and R packages were used to find the county and state name of the zip code (Rozzi, 2021). The state names were verified to match the names found through processing the tilde file, thus providing additional data assurance. This was used to create the map provided in Section 3.5.

Code was generated to heuristically determine the country of origin. This code searches for common country abbreviations in the address field and appends the country data field to records without a listed country. The address of all records assigned to a country were reviewed manually before amending the data.

A final data processing step was to merge companies. In this process a searching tool was created to look for similar company name fields. These were reviewed manually before updating a match. For example, an entry of Bowing LLC, would be matched with BOWING. Human judgment was made in combing records, and only obviously identical companies were updated. There may be bias introduced due to a lack of information about parent and child company relationships beyond identical names. Since there are likely to be some unmatched companies the standard errors of the company level regression may be overestimated. The coefficients will only be biased if the companies matched are systematically different for nuclear companies, and other companies. This is a plausible source of error since more effort was required to process the nuclear components data (as this was the key data) and this could result in more familiarity with the nuclear data resulting in more matches being made. While this is a potential issue, the cleaning process was the same for each group, only matching on obviously identical company. A future improvement to this data set would be to combine the companies with more detailed records of ownership, although this is likely to be a very time-consuming process.

With each data set collected records were aggregated to a state year panel. Certificates were aggregated into broad categorical types. All certificate with types N, N3, NA, NP, NS, NV, OWN, G, GC, and MO were classified as being nuclear related certificates based on ASME guidelines (American Society of Mechanical Engineers, n.d., 2022, 2023). All other certificate types were labeled as non-nuclear. Alternative specifications were tried by removing OWN, and NA types[98] from the nuclear classification as a robustness check.

[98] These types correspond to ownership and installation which are arguably not in the manufacturing sector. They are kept in the main regression because installing parts can be considered a step in the manufacturing process.



APPENDIX (B) LIST AND CLASSIFICATION OF NUCLEAR COMPONENTS

Table 16:
Major Structures, Systems, and Components used in Light Water Reactor Power Plants

Structures, Systems, and Components		Classification
Pneumatic Systems	Hydraulic Control Units (BWR)	Important to Safety
	Auxiliary Feedwater Control (PWR), SRVs (BWR)	Safety-Related
	Power Operated Relief Valves (PWR)	Safety-Related
	BOP Control Air	Safety-Related
	Control / Service Air	Industrial
Nuclear Steam Supply Systems	Up to the 2nd Main Steam Isolation Valve (MSIV)	Safety-Related
	2nd MSVI to Main Turbine	Seismic / Industrial
	MSIVs (ASME Class 1 for BWRs; Class 2 for PWRs)	Safety-Related
	Primary Coolant Pump / Primary System Piping (ASME Class 1)	Safety-Related
	Steam Generators (ASME Class 1)	Safety-Related
	Steam Drive Pumps (Aux Feedwater / Reactor Isolation Cooling	Safety-Related
Emergency Systems	Emergency Core Cooling / Pumps / Heat Exchangers (ASME Class 2)	Safety-Related
	Component Cooling Water (ASME Class 2)	Safety-Related
	Instrumentation / Power Distribution Switch Gear (IEEEa Class 1E)	Safety-Related
		Safety-Related
	Steam Driven Pumps	
	Isolation Condensers	Safety-Related
	Residual Heat Removal	Safety-Related
	Safety Injection System	Safety-Related
Essential Electrical Equipment (IEEE Class IE)a	Switchgear (120 AC, 4KV, 6 KV)	Safety-Related
	Power & Control Wiring	Safety-Related
	Vital DC, Batteries, Chargers, and Inverters	Safety-Related
Standby Diesel Generators	Diesel Generator Building	Safety-Related
	Standby Diesel Generators	Safety-Related
	Fuel Oil Transfer systems	Safety-Related
	Station Blackout Diesel	Important to Safety
	Fuel Oil	Important to Safety

Table 16 (Cont.):
Major Structures, Systems, and Components used in Light Water Reactor Power Plants

Structures, Systems, and Components		Classification
BOB Electrical Equipment	Switchgear (120 AC, 4KV, 6 KV) & DC Switchboards Main Generator Voltage Regulator and Transformers	Industrial Industrial
Fuel handling and storage	Fuel Storage Building (Fuel & Cask cranes, Monorails/Hoists, Fuel Elevator, Spent Fuel Transfer System, fuel pool liner, Dewater Prevention) Spent Fuel Racks Service platforms Fuel Pool Cooling (Pumps, Demineralizers, Filters) (ASME Class 2) Fuel Storage Building and Emergency Ventilation Systems Fuel handling tools	Safety-Related Safety-Related Safety-Related Safety-Related Industrial Safety-Related Safety-Related Important to Safety
Control Building	Control Room HVAC, Pressurization /Post-Accident Filtration and Monitoring Systems Local Panels & Cabinets Plant Control Systems Reactor Protection System (Class 1E) Process Computer Control Room Air Intake Structure	Safety-Related Safety-Related Safety-Related Safety-Related Important to Safety
Reactor Building	Containment Liner, Shield Building, Reactor Internals, Control Rods / Diver Mechanisms (ASME Class1) HCUs Mechanical (BWRs) Containment Purge and Vent System Reactor Cavity Cooling System Containment Spray Containment Sumps Containment Crane Combustible Gas Control System (BWR) Chemical Volume and Control System (PWR)	Safety-Related Safety-Related Safety-Related Safety-Related Safety-Related Important to Safety Safety-Related Safety-Related Safety-Related Safety-Related
Heat rejection systems	Ultimate Heat Sink & Pumps (ASME Class 3) Essential Heat Exchanger (ASME Class 2 / 3) Essential Cooling Towers Condenser Circulating Water System Cooling Towers & Basins Water Intake Equipment	Safety-Related Safety-Related Safety-Related Industrial Industrial

Table 16 (Cont.):
Major Structures, Systems, and Components used in Light Water Reactor Power Plants

Secondary Systems	Reactor makeup water system (ASME Class 2)	Safety-Related
	Reactor Water Clean Up (ASME Class 2)	Safety-Related
	Fluid Leak Detection System	Safety-Related
	Nuclear Service Water System	Safety-Related
	Sampling Equipment	Important to Safety
	Primary Component Cooling Water (ASME	Safety-Related
	Class 2 / 3)	Industrial
	Auxiliary Steam	
Radwaste processing	Liquid Waste System	Important to Safety
	Waste Gas Processing / Storage (ASME Class 2)	Safety-Related
	Solid Waste System	Important to Safety
	Radwaste Panels & Racks	Important to Safety
Turbine Equipment	Condensate Storage Facilities	Safety-Related
	Turbine Generator	Industrial
	Condensing System (ASME)	Industrial
	Feedwater Heating (ASME)	Industrial
	Feedwater Pumps (ASME)	Industrial
	Turbine Auxiliaries (Stator Cooling,	Industrial
	Generators Seal Oil, Turbine Lift Pumps)	Industrial
	Main Cooling Tower Makeup & Blowdown	Industrial
Structure & Improvements	Technical Support Center	Important to Safety
	Security Building	Important to Safety
	Turbine Building	Industrial
	Admin Building	Industrial
	Fuel Storage Building	Safety-Related
	Communications equipment	Important to Safety
	Fire Pump House Emergency Feedwater	
	Pump Building Radiological	Important to Safety
	Railroads	Industrial

Table 16 (Cont.): Major Structures, Systems, and Components used in Light Water Reactor Power Plants

Advanced Reactors

Structures, Systems, and Components		Classification
NuScale Equipment	Reactor pressure vessel	Safety-Related
	Containment Vessel	Safety-Related
	Reactor Coolant System	Safety-Related
	Decay Heat Removal System	Safety-Related
	Emergency Core Cooling System	Safety-Related
	Reactor Protection System	Safety-Related
	Containment Isolation System	Safety-Related
	Ultimate Heat Sink	Safety-Related
	Spent Fuel Pool Cooling and Cleanup System	Safety-Related
	Light-Load Handling System (Related To Refueling)	Safety-Related
	Overhead Heavy Load Handling System	Safety-Related
	Reactor Component Cooling Water System	Safety-Related
	Demineralized Water System	Industrial
	Potable And Sanitary Water Systems	Industrial
	Site Cooling Water System	Industrial
	Compressed Air System	Industrial
	Chemical And Volume Control System	Safety-Related
	Containment Evacuation And Flooding Systems (unique to NuScale)	Safety-Related
	Reactor building and spent fuel Pool Area Ventilation System	Safety-Related
	Radwaste Building Ventilation	Industrial
Liquid Metal Fast Reactor	Reactor Vessel Inert Gas System	Safety-Related
	Shutdown Cooling	Important to Safety
	Primary and Secondary Sodium Loops / Heat Exchangers	Safety-Related
	Energy Island (EI; BOP)	Industrial
	Molten Salt Isolation Valves and Instrumentation (between NI & EI)	Safety-Related Important to Safety
	Intermediate Air Cooling	Safety-Related
	Sodium Int. loop Sodium/Salt HXs	Safety-Related
	Spent Fuel Pool (water)	Safety-Related
	Reactor Air Cooling / Reactor Cavity	Safety-Related
High Temperature Gas Reactors	He Purification Equipment	Important to Safety
	He Circulator (ASME Class 1)	Industrial
	Primary System Piping (ASME Class 1)	Industrial
	Steam Generators	Safety-Related
	Inert Gas System	Safety-Related
	Steam Generator (ASME Class 1)	Safety-Related
	Electrical / Control (IEEE Class 1E	Safety-Related

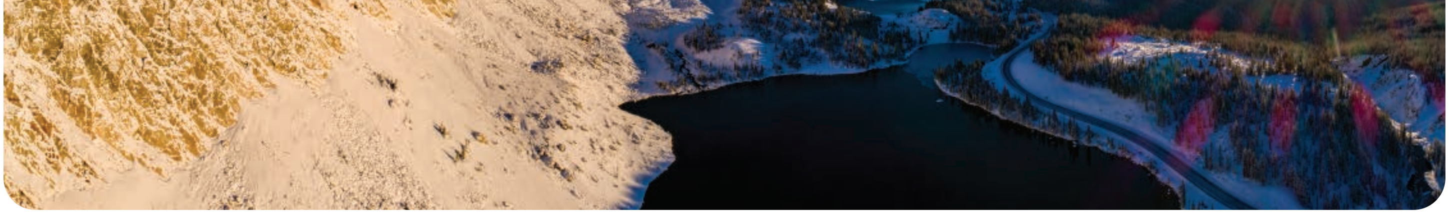


Table 17:
Small Industrial Grade Components Used in non-Safety SSCs[99]

Anchor Bolt	Limit Switch	Shaft Coupling
Ball Bearing	Lubricating Grease	Solenoid Valve
Bolting	Material Plate Angle	Spiral Wound Gasket
Control Switch	Motor	Spring
Cotter Pin	Diaphragm	Temperature Switch
Crane Wheel Axle	O-Ring	Terminal Block
Drive Belt	Pinion Gear	Terminal Connector
Frame Device	Pressure Switch	Torque Switch
Fuel Oil	Pump Impeller	Transistor
Fuse	Pump Mechanical Seal	Transmitter
Impeller Key	Relay	Valve Packing Gland
Integrated Circuit	Resistor	Valve Seal Ring
Filter Regulator	Roller Spring	Valve Stem

Table Notes:

[a] IEEE: Institute of Electrical and Electronics Engineers, established a series of "Class 1E" Codes and Standards for safety-related electrical components. 10 CFR 50.55a mandates these IEEE Codes and Standards for domestic licensees, similar to ASME BPV Code (III) requirements for mechanical components.

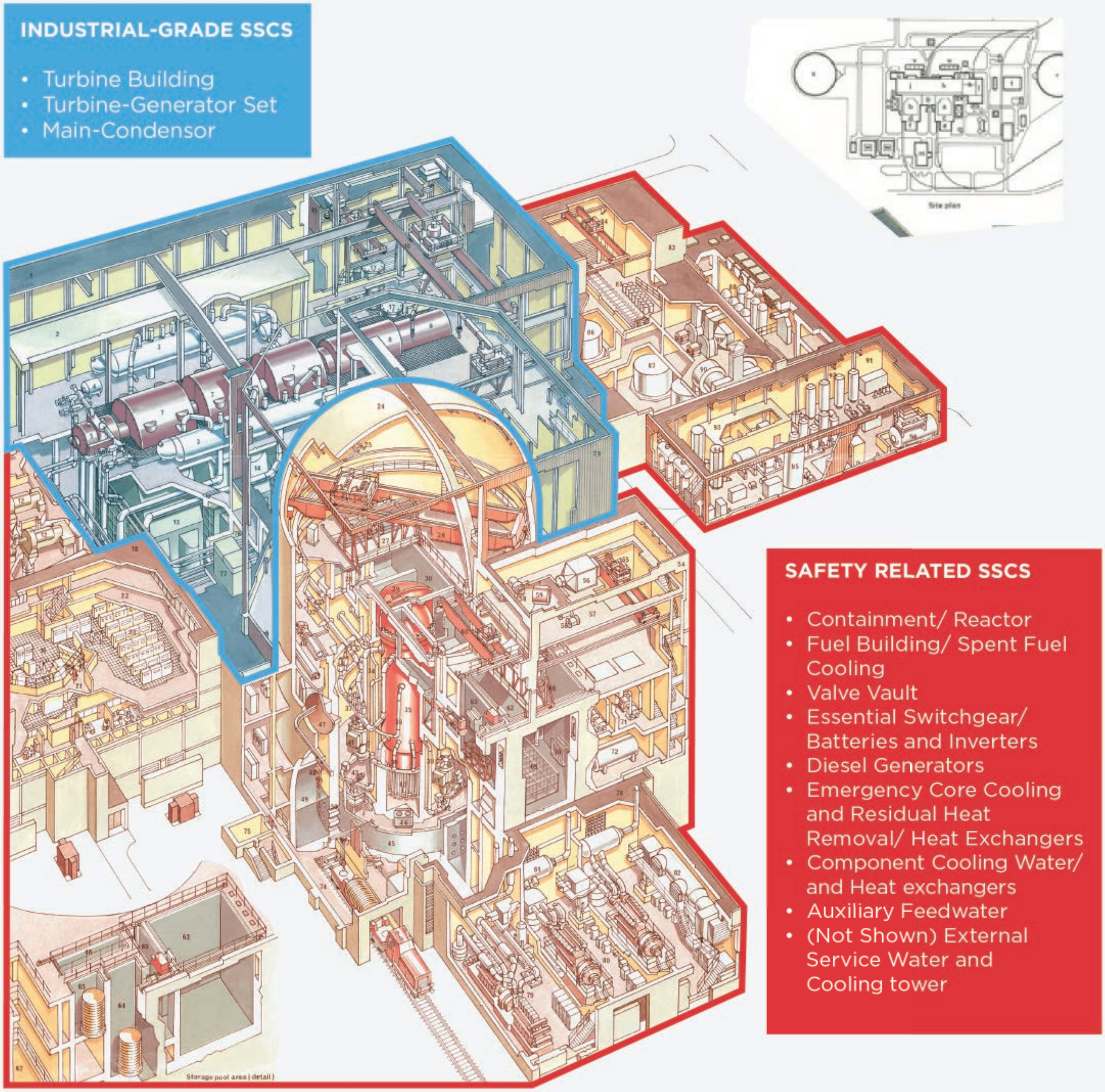
[b] Per NRC (https://www.nrc.gov/reactors/new-reactors/smr/licensing-activities/nuscale/ser-open-items.html)

[c] Specifically apply to the proposed TerraPower Natrium Sodium-Cooled Fast Reactor

[d] The proposed BWXT is a high temperature gas (Helium cooled) micro-reactor

[99] Required per 10 CFR 50 10 CFR 50.63(a)(1), "Loss of all alternating current power" (https://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-0063.html).

Figure 24:
Pressurized Water Reactors -Structures, Systems, and Components Classifications[100]



[100] (Nuclear Engineering International, 1980) under https://creativecommons.org/licenses/by/2.0/ red and blue lines added for emphasis.

APPENDIX (C) POISSON COEFFICIENT INTERPRETATION

This appendix provides more details about the rationale for the applied regressions. The goal of this research is to identify what advantages or barriers are present in Wyoming for the development of a nuclear component manufacturing sector. Proper interpretation of the econometric results is necessary if the results are to be applicable to policy decisions.

The coefficient estimates of the Poisson model of ASME certificates is argued to represent a change in nuclear component diversity. The number of ASME nuclear certification is the combination of the total number of nuclear component firms, and the number of product types produced by these firms. Only under strict assumptions do these coefficients also predict the output of the nuclear components sector. Under the more relaxed assumption of monotonicity, the coefficients predict an ordinal rank of state output levels. Care should be taken when expanding this to the GDP output level. In totality, the estimate of firm diversity is useful for identifying the ease of entering the nuclear component market, and the estimates can be applied to the ranking of state component output.

In the most literal sense, the models predict the number of ASME nuclear certifications in a given state and year. This outcome is not the same as the level of nuclear component production, but it still provides valuable information. States without active ASME nuclear certification lack a nuclear component sector[101], while active certificates indicate that a state is part of the supply chain. Even if the company with a certificate is not actively producing parts, they are a part of the nuclear components supply curve as defined in economic terms. Such companies will be willing to produce these parts if prices rise to a profitable threshold. Holding the N-stamp indicates the firm considers this production a possibility. This provides some policy implications without further assumptions. Increasing the number of certificates in a state also increases the probability of the State being actively involved in nuclear component supply chain.

[101] Two exceptions exist, if generic parts are constructed, or if some manufacturing skips the N-stamp procedure. Both cases are the exception and not the industry norm.

When some basic assumptions are applied to the model, the implications of the result are expanded. The number of certificates can be viewed as an index of nuclear component manufacturing diversity. The coefficient estimates are best interpreted as the elasticity of firm product lines. Each ASME N-stamp is an addition of a new company to the sector, or the addition of a product line from an existing nuclear components company. Both changes contribute to sector diversity, either by increasing how competitive the market is (more firms) or by increasing product ranges (more types of nuclear components produced). For the policy goal of developing a nuclear component sector in Wyoming, this measure of industry diversity is germane. As was seen in previous research, acquiring large nuclear supply chain facilities can be challenging (Gebben & Peck, 2023). If the policy goal is to establish a robust sector in the State, the N-stamp intensity avoids the pitfall of overweighting exceptionally large nuclear component facilities when the ability to attract such companies is highly limited. The development of a nuclear component industry with many firms and product types is of interest to policy makers even if this does not correspond one-to-one with sector level output.

Further this is the most appropriate measure when estimating the advantages and barriers to establishing a nuclear component sector. The diversity of nuclear component firms is more suggestive of a low barrier to entry than pure output. This segment of the analysis attempts to establish the factors that allow entry into the market. For that goal, the existence of many small firms is a better indicator that the State has amenable attributes to start a nuclear component sector than the output of those firms.

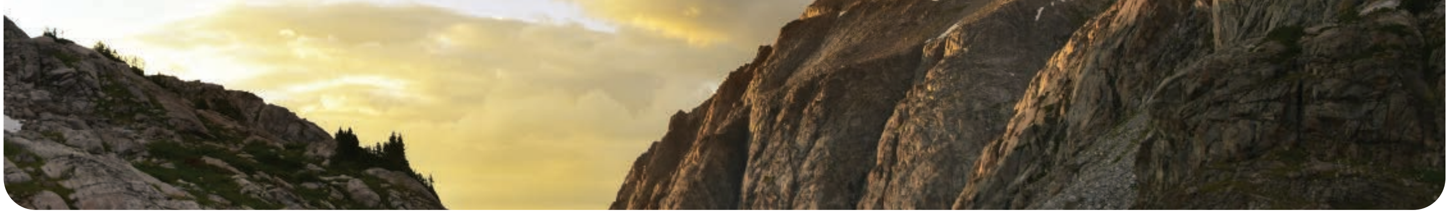
The results may be extended to output levels under even more restrictive assumptions. If there is a predictable covariance function between nuclear component certificate rate and nuclear component GDP, then there is a way to transform the number of certificates to sector output. An intuitive assumption would be that ASME N-stamps are linearly related to total output. A company that applies for a nuclear certificate has some probability distribution of the final level of component output. Sometimes the firm develops into a large company and other times they remain idle. If each certificate has the same expected probability distribution of outcomes, then adding a N-stamp to a state is linearly related to output. By chance some of these firms develop large lines, but the addition of any single N-stamp has the same expected outcome prior to seeing how the firm develops. If this reasoning is followed, then the coefficient estimates of the Poisson model can be interpreted as the effect on industry output (although this assumption is not made in the current analysis).

This narrow assumption can be relaxed. It is possible to predict an expansion path of N-stamp to nuclear component manufacturing that is non-linear. A plausible outcome is that there is a constant elasticity of production to nuclear component certification. Adding one more N-stamp to a state with many N-stamps indicates a large product line is added, since the sector is already saturated. In a State with very few N-stamps these new product lines may be low hanging fruit such as small valves or pipes. While an estimated expansion path is not undertaken in this analysis, future research can extend the present analysis through a micro economic model that maps N-stamps to industry output.

A reasonable assumption that is made about the production response to nuclear certification is that it is strongly monotonic. That is, any given state will increase new nuclear component output if a nuclear certificate of any type is added. It may be that a NA[102] type certification adds less production than an OWN[103] type certificate, but adding either certificate, all else equal, increases production. Under this plausible assumption the Poisson estimates does predict the ranking of importance of each factor to firm output. For example, reducing corporate tax rates by 2% is found to increase the number of nuclear certifications by 0.6%. Increasing nuclear power in a state by 2% is predicted to increase the number of certificates by 0.16%. From the monotonic assumption it follows that a state with 2% lower corporate taxes will have more production than a comparable state with 2% higher taxes but 2% lower nuclear output. What cannot be said is that this difference will be 0.44% of total output. The coefficient cannot be interpreted directly as production levels, but a larger coefficient always implies the variable has a larger effect on final nuclear component output.

Taken together the Poisson coefficients are treated as being the elasticity of firm and product diversity in nuclear component manufacturing of a State. The coefficients provide insight into which variables create barriers or advantages to attracting new firms engaged in a wide range of nuclear component manufacturing. Positive coefficients imply an increase in the nuclear component sector output along the given vector. However, the relationship between certificates acquired and sector GDP output is not taken to be linear (without more data). The model should be applied to component manufacturing output with this in mind.

[102] This is a certification for installation of nuclear components.
[103] This is a certification for ownership of nuclear powerplants.



APPENDIX (D) MODEL DESCRIPTION

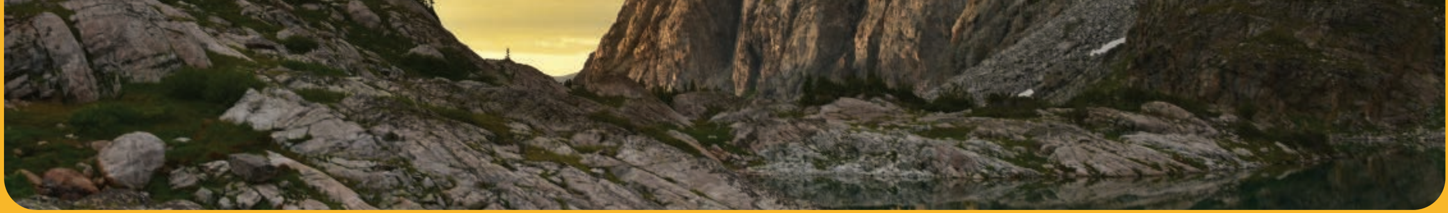
In this appendix the details of the Poisson regression are provided, with a complete explanation of model choices. A Poisson regression provides more consistent coefficient estimates than linear regression when the distribution of outcomes are positive whole numbers. However, linear regressions will yield comparable results if there are many possible outcomes[104] (Wooldridge, 2019).

To decide if a Poisson regression is appropriate a summary statistics table is provided in Table 18. Because the regression is estimating the number of certificates in a state per year, the outcome variables are binned accordingly. The number of certificates acquired is separated into the nuclear category, and all other certificates.

Table 18:
Distribution of the Number of New ASME Certificates

Characteristic	**Nuclear,** N = 1,584[1]	**Non-Nuclear,** N = 1,584[1]
ASME Certificates in a Given State and Year		
0	1,449 (91%)	612 (39%)
1	69 (4.4%)	275 (17%)
2	34 (2.1%)	211 (13%)
3	18 (1.1%)	144 (9.1%)
4	10 (0.6%)	87 (5.5%)
5	3 (0.2%)	83 (5.2%)
>5	1 (<0.1%)	172 (11%)
[1] **n (%)**		

[104] For example, if there are outcome values that range from 1 to 1000 and the higher values are well represented, a linear regression may be sufficient for estimating the model.



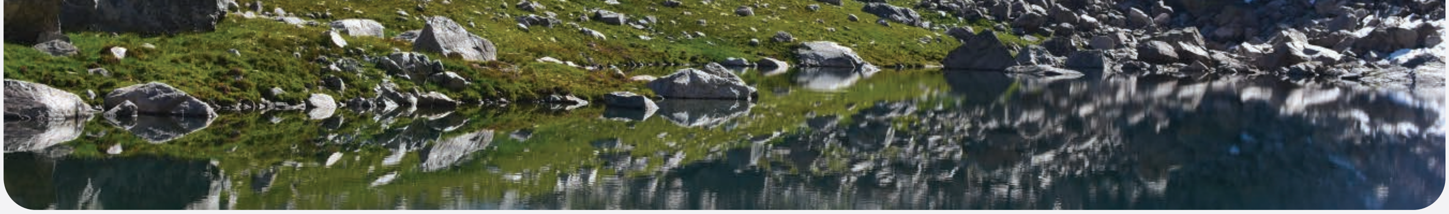
The distribution of outcomes shows that a Poisson model is more appropriate than a linear regression. The outcome variable of nuclear component certificates is zero 91% of the time. Zero is the mode for both certificate types. The distribution is skewed towards lower values, with state-years with only one entry representing 4.4% of all data points. The number of entries declines as the certificate numbers increase. Because only one entry has more than five nuclear certificates, a linear regression will have inefficient standard errors, and biased coefficients. A Poisson model corrects for this providing efficient estimates.

Next the variables selected will be explained. In the preferred model state and year fixed effects are included. This removes the need to include time invariant state attributes in the model. This strengthens the model results but restricts which outcomes can be predicted. For this reason, the following variables were not included: state size, access to maritime trade dummy, corporate tax dummy, temperature effects, and nameplate capacity. These effects are either colinear with fixed effects or are nearly colinear.

In the case of nameplate capacity and temperature there is the capability to estimate a within state effect, but these would be misleading coefficients. The planned addition or retirement of nameplate capacity is well known in advance, leading to anticipation effects. More importantly there are very few shocks in nameplate capacity. A recent example of a shift in expected capacity occurred in 2022, due to war in Eastern Europe. This resulted in an increase in the price of natural gas, due to supply constraints. As a result, the price of electricity increased, leading to the retirement date of many coal power plants to be shifted out. While events like this can induce changes to the inelastic power sector, such changes are captured by the year fixed effects. Most of the policy effects in states are consistent over time and so are captured by the state fixed effects. The remainder of this effect is expected to be primarily noise. The nameplate capacity is included elsewhere because it captures some of the state location and policy effects.

Temperature effects are also excluded from this model even though there is variation across states and years. This is done based on the behavior of firms that maximize profits. Year to year changes in weather are inherently stochastic. Any variation from historic norms in weather does not change expectations of future weather. An unseasonably cold winter this year does not suggest that the next winter will be similarly cold. However, the average temperature over many winters can be used to predict the temperature in future winters. A manufacturing firm selecting a location for a new facility will therefore consider only the long run average weather in a state. These weather effects operate on the long-term margin, making them colinear with the state fixed effects. In other industries like natural gas production, year to year affects matter. A colder than average winter will increase natural gas prices in that year, and consequently production. However, there is no plausible mechanism by which the demand or supply of nuclear components is affected by short term weather changes.

The variables included in the state-year fixed effect model are corporate taxes collected, manufacturing employment levels, unemployment rates, population, and the level of non-nuclear certificates acquired in a year.



The amount of corporate taxes collected (in dollar terms) is selected over the alternative of corporate tax rates (percentage). The amount of corporate taxes collected by the state is not perfectly reflected by the corporate tax rate. For example, a state with a 10% corporate income tax rate may collect fewer taxes from an identical firm than a state with a 5% tax rate if the former state has a moratorium on income taxes for certain types of production, or for a certain number of years. All else equal a nuclear component manufacturing firm will prefer to build a new facility in the state with a 10% corporate tax rate if the effect of the moratorium and incentives reduces the effective tax rate to 4%. This effective rate is identified through the dollar value of taxes collected on corporations.

The year fixed effect controls for national economic recession or expansion which affect the taxes collected. Localized economic changes are captured through the population coefficient. After controlling for these national economic trends, the corporate tax coefficient estimates the state specific changes on effective taxes paid from state policy.

Data was collected for other tax rates including property taxes. The data for property taxes is more limited so the number of observations is reduced when this term is included. Also, property tax rates do not directly isolate the taxes paid by corporations which is a more relevant measure of taxes paid by manufacturing firms. Once the state and year fixed effects are included, the corporate tax rate coefficient provides a good, generalized estimate of the effect of tax changes. An equivalent effective tax rate hike in other types of taxes affects the bottom line of firms in the same manner as a corporate tax rate hike. This means the results can be applied more broadly than to corporate tax rates. When applying these results to other taxes it is important to adjust for the particulars of the tax including available write offs, and exemptions.

Controls for population were also included. This variable is not assumed to be causal. An increase in population reflects a wide range of economic trends, including job availability, standards of living and state policy. It is assumed that any given state has a fixed manufacturing output per capita. If Wyoming grows by 10% all else equal there is likely to be 10% more component certificates. However, the effect varies because growing or shrinking populations indicate a change in underlying state characteristics. While the reasons behind the population growth are not ascertained by the regression, population is an important control to avoid biasing the other coefficients. Generalized national population trends are captured by the year fixed effects. The population variable estimates the effect of state specific migration that deviates from the national average.

Manufacturing employment is included to establish how manufacturing growth affects nuclear certification levels. If nuclear ASME certification follows the same trends as general manufacturing the coefficient will be significant. If for example the nuclear component firms are identical to the general population of manufacturing firms, an increase in manufacturing levels will be a perfect predictor of ASME nuclear certificates. This control is endogenous with corporate tax rates, and for the purpose of predicting the effect of tax rates, a model with this variable removed is preferred. While endogeneity with the

outcome variable is possible, the nuclear ASME certified firms are a small portion of employment even in states with an existing manufacturing sector, so the effect is primarily one way.

The unemployment rate is included to capture the remainder of the local economic changes affecting a state. This term is insignificant because most of the unemployment effect is controlled by the year fixed effect, and the population coefficient. The unemployment rate is available for all states over the period studied, so including this variable does not reduce the "n" of the regression. The cost of including this term is low, even though the results are not significant.

The rate of non-nuclear certification is also included as a control. This captures any changes to the value of ASME certificates that are specific to a state. For example, Wyoming may establish standards that make ASME certification more valuable to firms. Removing these potential biases improves the overall estimate, although this value is not found to be statistically significant.

The second model applies a similar Poisson regression but drops the state fixed effects. As a result, more controls are included. Dropping the state fixed effect allows for the impact of state characteristics to be observed. This comes at the cost of requiring controls for variables that are constant across time for each state. The primary effect of weather and nameplate capacity are fixed at the state level and so are included in this model. For weather: heating degree days, cooling degree days, and natural disaster direct deaths are used. Average temperature is not included, because this effect is nonlinear. People prefer to locate in moderate climates, raising the average temperature in a cold state would induce more development, but the same temperature change in a hot state will decrease development. The heating and cooling days segregate uncomfortable weather, a state with a high average number of cooling degree days has many days that are hot enough to require air conditioning. A state with many heating degree days has many days where home heating is used, and/or days of intense heating requirements. Isolating the effects of hot and cold weather provides a more robust estimate.

The number of direct deaths due to natural disasters is considered the best value to represent the effect of catastrophic events. Companies selecting a site for a manufacturing facility consider the risk of catastrophic events. All else equal locations with a high probability of hurricanes will have higher insurance costs, and higher risk of facility damage. The damage to buildings from hurricanes, floods, fires, and tornadoes are highly correlated with total death rate. Alternatively, the amount of property damage caused by natural disasters was collected from the NOAA data set. Death rates are preferred to property damage measures because firms are more concerned with local severe weather events, than broad but moderate events. A typical frost event can cause significant property damage, by causing car accidents or destroying crops. Yet such an event would not cause damage to a typical manufacturing facility. Events that cause direct deaths on the other hand, are more associated with catastrophic events that can damage a large manufacturing facility.

Nameplate capacity is included as an indicator of regional economic effects unique to power generation. More nuclear nameplate capacity is expected to drive components manufacturing firms to locate regionally, due to network effects. General nameplate capacity can contribute to these network effects, and captures a slew of state attributes, such as the size of the electricity grid, and policies that affect power companies. To account for spillover effects, the nameplate capacity of neighboring states is included. These coefficients should be interpreted carefully, as general nameplate capacity is capturing more than the direct development effects of added capacity.

The state's size is included because a state's population density affects land prices and labor availability, different from average population levels.

Two additional dummy variables besides the year fixed effect are included. A dummy for a state being on the coast is included. Access to maritime trade is an advantage to manufacturing operations, inputs can be purchased more cheaply, and finished products can be sold to the market with lower transportation costs. However, being on the coast is correlated with hurricanes. To better predict the coefficient of natural disasters, this dummy is included. A state like Maine has the benefits of easy access to the coast but has fewer natural disasters than a state like Florida. This dummy accounts for the average effect of a state being on the coast, disentangling this effect from natural disaster effects.

The second dummy is one if a State never had a corporate income tax. States without a corporate income tax, such as Wyoming, commonly apply other types of taxes to corporations. For example, Wyoming is one of few states that has a tax on stored corporate property. Without the State fixed effect controls the corporate income tax estimate will be biased. States with an apparent zero corporate tax rate have an uncertain tax rate due to unique tax structures. Including this dummy removes the mean effect of these other types of taxes.

Since fixed effects are included, there is the potential to underestimate the model standard errors unless the errors are clustered. The models selected use heteroskedastic robust, state and year clustered standard errors. This is deemed to be a conservative estimate since it allows for correlations across time within states. However, it is likely that clustering at the state level is sufficient. Alternative clustering methods are applied in Table 19 and Table 20. The results suggest that the selected model standard errors are robust. There are no coefficients in the model deemed to be statistically significant that become insignificant under alternative standard errors handling. In fact, some attributes such as natural disaster deaths are significant if clustering is not done.

Table 19:
Alternative Standard Error Estimates in State & Year Fixed Effects Model

Dependent Variables	Nuclear Certifications				
Model	(1) Poisson	(2) Poisson	(3) Poisson	(4) Poisson	(5) qauasipoisson ("log")
Variables					
Corporate Tax	-0.273** (0.119)	-0.273*** (0.103)	-0.273** (0.133)	-0.273** (0.108)	-0.273** (0.135)
Manufacturing Employment	1.47 (0.938)	1.47 (1.05)	1.47 (1.08)	1.47 (0.907)	1.47 (1.13)
Unemployment	0.059 (0.130)	0.059 (0.145)	0.059 (0.110)	0.059 (0.093)	0.059 (0.117)
Population	4.64* (2.52)	4.64* (2.35)	4.64* (2.17)	4.64*** (1.51)	4.64* (1.88)
Other Certificates	0.016 (0.022)	0.016 (0.025)	0.016 (0.025)	0.016 (0.020)	0.016 (0.025)
Fixed-effects					
Year	✓	✓	✓	✓	✓
State	✓	✓	✓	✓	✓
Fit Statistics					
Standard-Errors	**State & Year**	**State**	**Year**	**IID**	**IID**
Observations	898	898	898	898	898
Squared Correlation	0.26856	0.26856	0.26856	0.26856	0.26856
Pseudo R^2	0.26901	0.26901	0.26901	0.26901	0.26901
BIC	1,430.5	1,430.5	1,430.5	1,430.5	1,430.5

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Table 20:
Alternative Standard Error Estimates in Year Fixed Effect Model

Dependent Variables	Nuclear Certifications				
Model	(1) Poisson	(2) Poisson	(3) Poisson	(4) Poisson	(5) qauasipoisson ("log")
Variables					
Corporate Tax	-0.267*** (0.084)	-0.267*** (0.077)	-0.267*** (0.098)	-0.267*** (0.067)	-0.267*** (0.090)
Nameplate Capacity (NPC)	0.461 (0.417)	0.461 (0.468)	0.461 (0.322)	0.461* (0.274)	0.461 (0.370)
Nuclear NPC	0.080** (0.036)	0.080** (0.035)	0.080*** (0.026)	0.080*** (0.019)	0.080*** (0.026)
Other Certificates	0.031 (0.022)	0.031 (0.028)	0.031 (0.021)	0.031 (0.019)	0.031 (0.025)
Manufacturing Employment	0.956*** (0.254)	0.956*** (0.302)	0.956*** (0.235)	0.956*** (0.203)	0.956*** (0.274)
Unemployment	-0.117 (0.112)	-0.117 (0.117)	-0.117 (0.072)	-0.117* (0.061)	-0.117 (0.083)
Boarder NPC	-0.013 (0.058)	-0.013 (0.075)	-0.013 (0.062)	-0.013 (0.050)	-0.013 (0.068)
Boarder Nuclear NPC	0.106 (0.083)	0.106 (0.096)	0.106 (0.077)	0.106** (0.050)	0.106 (0.067)
Natural Disaster Deaths	-0.554 (0.356)	-0.554 (0.366)	-0.554** (0.238)	-0.554*** (0.182)	-0.554** (0.246)
Avg HDD	-0.704 (0.467)	-0.704 (0.513)	-0.704* (0.375)	-0.704** (0.296)	-0.704* (0.399)
Avg CDD	-0.630 (0.557)	-0.630 (0.623)	-0.630 (0.406)	-0.630** (0.310)	-0.630 (0.418)
State Size	-0.243 (0.231)	-0.243 (0.223)	-0.243 (0.168)	-0.243** (0.119)	-0.243 (0.160)
Fixed-effects					
Year	✓	✓	✓	✓	✓
Has Corporate Tax	✓	✓	✓	✓	✓
Coastal	✓	✓	✓	✓	✓
Fit Statistics					
Standard-Errors	State & Year	State	Year	IID	IID
Observations	1,362	1,362	1,362	1,362	1,362
Squared Correlation	0.21424	0.21424	0.21424	0.21424	0.21424
Pseudo R^2	0.26373	0.26373	0.26373	0.26373	
BIC	1,464.3	1,464.3	1,464.3	1,464.3	

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

APPENDIX (E) POISSON MODELS WITH DROPPED COEFFICIENTS

Table 21:
Alternative State Fixed Effect Controls

Dependent Variables	Nuclear Certifications						
Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variables							
Corporate Tax	-0.273** (0.119)	-0.309*** (0.111)	-0.312*** (0.111)	-0.166* (0.091)	-0.173* (0.091)	-0.321*** (0.113)	-0.160* (0.091)
Manufacturing Employment	1.47 (0.938)						2.31 (0.694)
Unemployment	0.059 (0.130)	0.023 (0.149)					
Population	4.64* (2.52)	5.65*** (2.18)	5.71** (2.23)			5.73*** (2.21)	
Other Certificates	0.016 (0.022)	0.026 (0.022)	0.026 (0.024)	0.027 (0.022)			
Fixed-effects							
Year	✓	✓		✓	✓		✓
State	✓	✓		✓	✓		✓
Fit Statistics							
Standard-Errors	State & Year						
Observations	898	927	927	927	927	927	898
Squared Correlation	0.26856	0.26453	0.26364	0.25307	0.24762	0.25817	0.25592
Pseudo R^2	0.26901	0.26677	0.26671	0.25242	0.25088	0.26528	0.25884
BIC	1,430.5	1,458.8	1,452.0	1,465.1	1,460.4	1,447.2	1,424.0

Clustered (State & Year) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

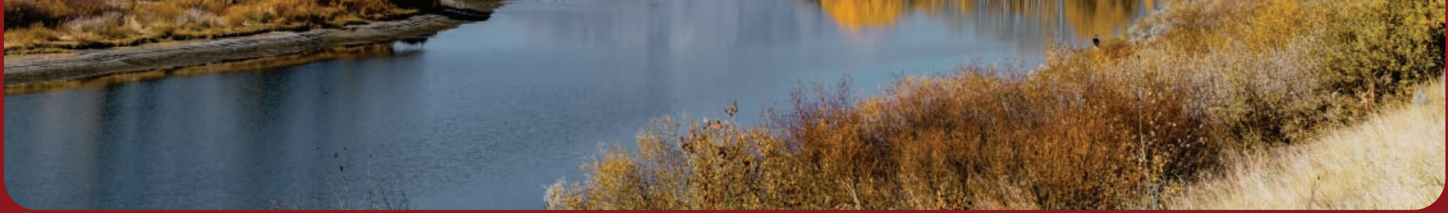


Table 22:
Alternative Year Fixed Effect Controls

Dependent Variables	Nuclear Certifications			
Model	**(1)**	**(1)**	**(1)**	**(1)**
		Variables		
Corporate Tax	-0.287*** (0.089)	-0.238** (0.096)	-0.206* (0.120)	-0.333*** (0.086)
Nameplate Capacity (NPC)	0.298 (0.475)	0.932** (0.429)	0.782** (0.396)	-0.149 (0.369)
Nuclear NPC	0.077** (0.035)	0.105*** (0.038)	0.068* (0.038)	0.064 (0.040)
Other Certificates	0.031 (0.021)	0.041 (0.025)	0.035 (0.026)	0.033 (0.025)
Population	0.336 (0.592)			1.21*** (0.369)
Manufacturing Employment	0.781** (0.357)			
Unemployment	-0.116 (0.112)	-0.068 (0.114)		
Boarder NPC	0.002 (0.060)	-0.049 (0.067)		
Boarder Nuclear NPC	0.087 (0.086)	0.156* (0.087)		
Natural Disaster Deaths	-0.539 (0.338)	-0.466 (0.267)	-0.179 (0.278)	-0.346 (0.305)
Avg HDD	-0.533 (0.579)	-0.414 (0.376)	0.316 (0.349)	0.346 (0.353)
Avg CDD	-0.478 (0.679)	-0.824* (0.433)	-0.115 (0.408)	0.150 (0.469)
State Size	-0.220 (0.235)			

Fixed-effects

Year	✓	✓	✓	✓	✓
Has Corporate Tax	✓	✓	✓	✓	✓
Coastal	✓	✓	✓	✓	✓

Fit Statistics

Standard-Errors	State & Year			
Observations	1,362	1,391	1,391	1,391
Squared Correlation	0.21424	0.18201	0.15822	0.18883
Pseudo R^2	0.26373	0.24228	0.22550	0.24721
BIC	1,464.3	1,507.4	1,512.5	1,485.0

Clustered (State & Year) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

APPENDIX (F) VECM MODEL OF US AND FOREIGN ASME CERTIFICATION

To determine the long run relationship between the U.S. nuclear component market and the global market a time series analysis is undertaken.

A Vector Error Correction Model (VECM) is implemented finding the relationship between uranium price, and the number of ASME nuclear certificates in the U.S., and all other foreign markets. A spurious regression results when the levels of times series are predicted, and those data points are non-stationary. In this case there is an expectation that shocks to the number of nuclear certificates in the U.S. and in all other countries, will share a long run relationship. If there is an underlying shock to the nuclear component market, that first effects European certification levels, the U.S. firms will eventually respond to this shock. In the long run a shock to one market will converge to the same dynamic of the two. If this dynamic holds a VECM can be applied which allows the level data to be used without a spurious regression.

The model uses errors in the VAR model as an input to find a short run and long run relationship. The natural log of all variables is used in the VAR model, and a trend term is included. Six months of lags are selected for the model based on the AIC criteria. However, for such a model to hold, the hypothesis that a cointegrating relationship cannot be rejected. A Johansen test is applied to the VAR model to test the validity of using a VECM (Johansen, 1988; Osterwald-Lenum, 1992). The results are provided in Table 23.

Table 23:
Johansen Test of Co-integration

	Test	10%	5%	1%
r <= 2	10.93	10.49	12.25	16.26
r <= 1	55.93	22.76	25.32	30.45
r <= 0	116.64	39.06	42.44	48.45

The hypothesis that all variables are cointegrated cannot be rejected at the 10% level, and the hypothesis of at least one cointegrating equation cannot be rejected at the 1% level. Test of serial correlation cannot reject the hypothesis of no correlation at 12 or 16 month intervals. Applying the error correction to the VAR produces the eigenvectors in Table 24.

Table 24:
Eigenvectors Normalized to Uranium Price

	Uranium Price	US	Foreign	Trend
Uranium Price	1	1	1	1
US	-0.0482	0.0307	-0.1640	-0.0808
Foreign	0.0326	0.0160	-0.1740	0.0335
Trend	-0.0002	0.0001	-0.0004	0.0088

Three main results are presented from the model. Figure 24 and Figure 25 plot key impulse response functions. Figure 24 plots the impulse response of U.S. certification level, from a shock in foreign nuclear certification levels, and Figure 25 provides the opposite response. Figure 26 plots the forecasted error decomposition over three years for each variable.

Figure 25:
Orthogonal Impulse on US Nuclear Certificates from Foreign Certificates
(Results of model shown overtime)

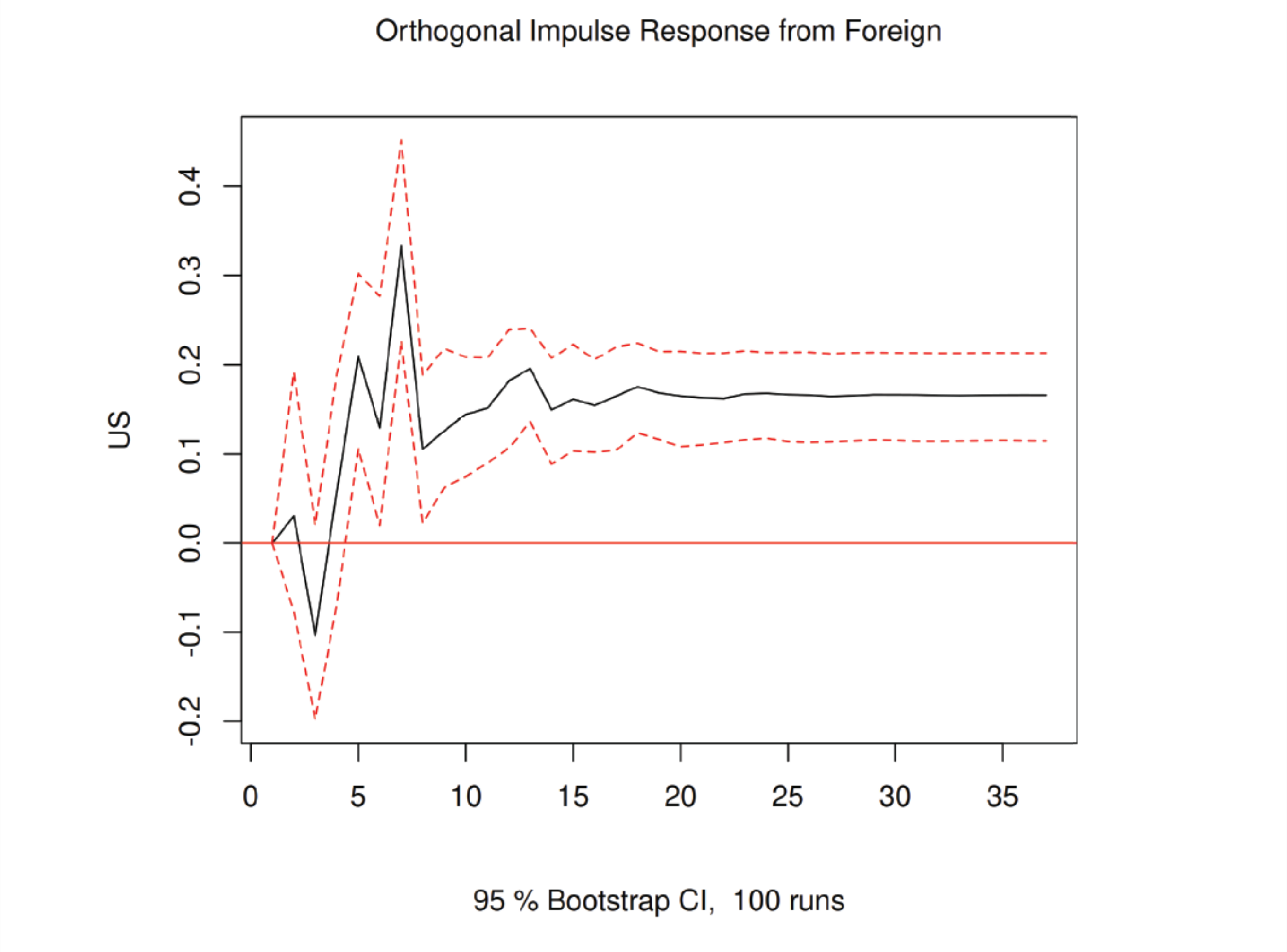


Figure 26:
Orthogonal Impulse on Foreign Nuclear Certificates from US Certificates
(Results of model shown overtime)

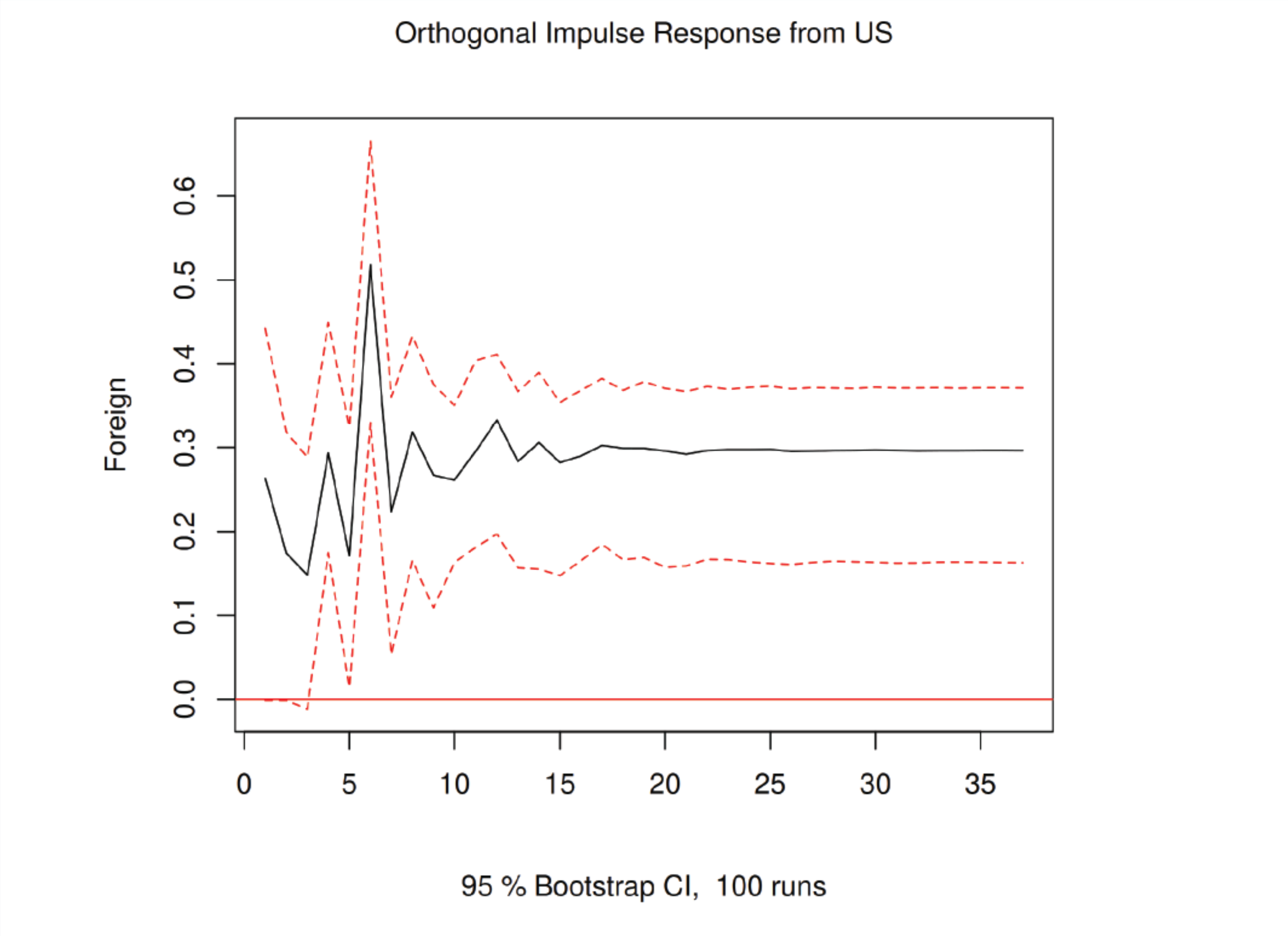
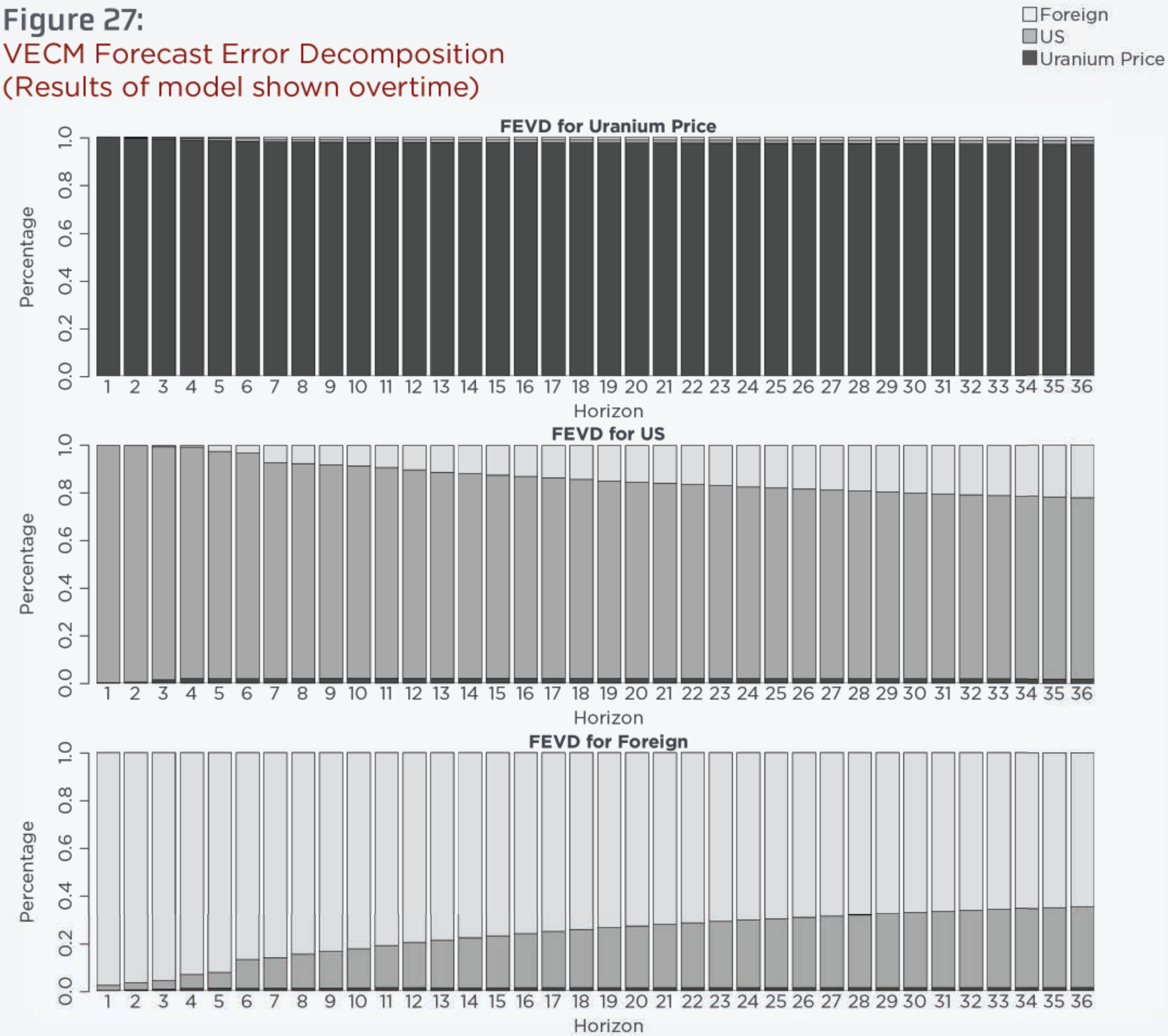


Figure 27:
VECM Forecast Error Decomposition
(Results of model shown overtime)



These results suggest that there exists a long run relationship between U.S. nuclear component manufacturing and global manufacturing levels. While uranium prices have a relationship with the two forms of nuclear component certification rates, they do not respond significantly to nuclear component production levels. About 20% of the United States component certification levels can be explained by shocks in the global market after three years. Most of the future certification levels can be explained by general trends, and shocks to U.S. certification rates.

For the analysis of economic barriers to developing nuclear components in Wyoming, the key results are that there does exist a cointegrating long run relationship between nuclear component manufacturing in each region. This suggests that small components are more of a global commodity than large components which are identified as regionally constrained. A trend term is included, which accounts for the average shift from the U.S. to foreign production. Both factors are relevant to discerning the key market factors affecting long-term growth prospects in the State.

APPENDIX (G) SUMMARY OF ASME CERTIFICATION RATES FOR NUCLEAR INVOLVED FIRMS

Table 25:
Diverse vs. Specialized Nuclear Components Manufacturing Summary

	Nuclear Components		NPT: Nuclear Partials		NAC: Nuclear Installation	
	Both	**Only Nuclear**	**Both**	**Only Nuclear**	**Both**	**Only Nuclear**
Fraction of Total	43.73%	35.03%	33.03%	31.92%	19.57%	11.30%
Active Certificates	74.83%	73.39%	74.07%	70.80%	71.88%	80.00%
Avg Issuance Date	2009-07-10	2010-12-20	2009-07-06	2010-08-13	2011-01-17	2012-02-17

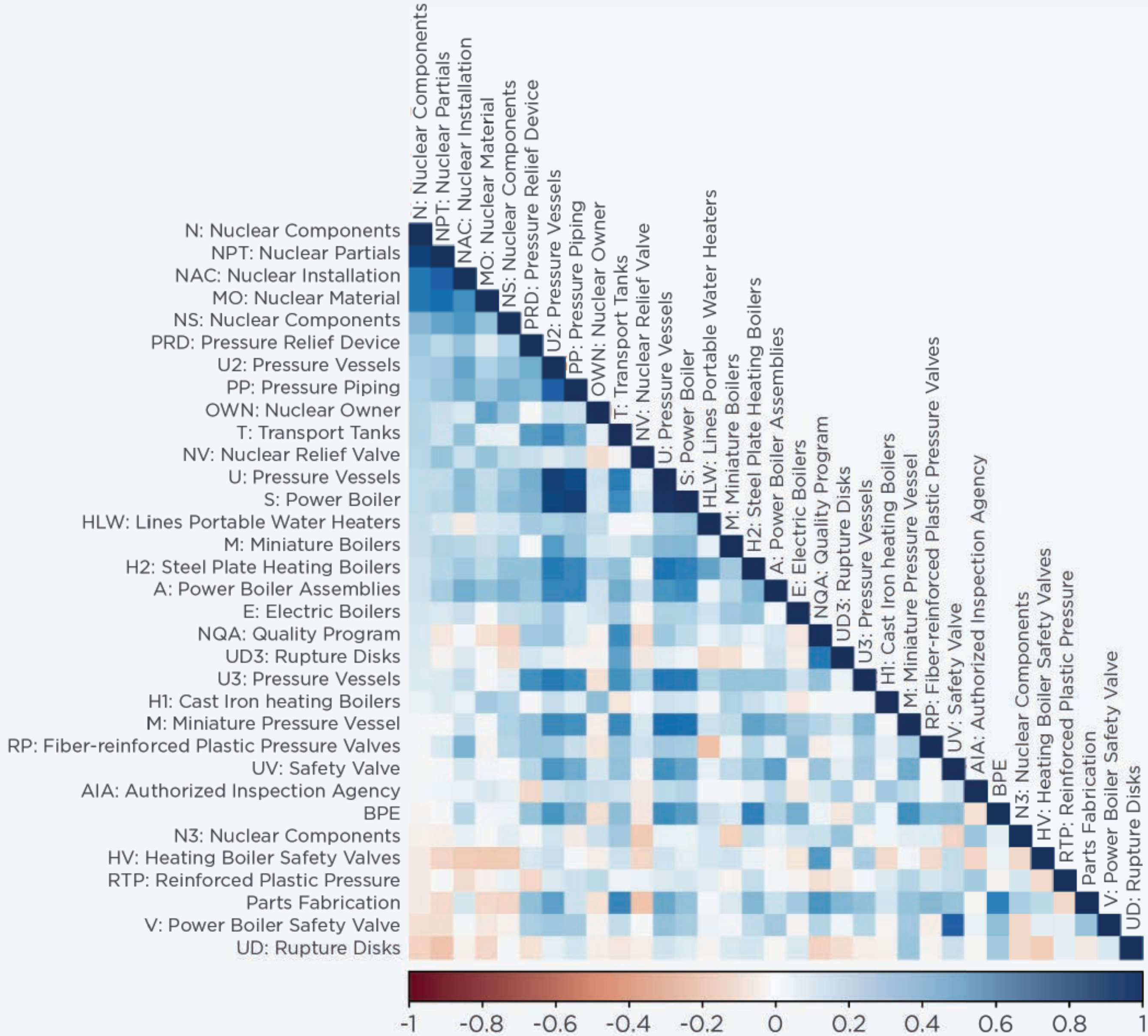
	Difference Between the Both Group and the Only Nuclear Group		
Fraction of Total	8.70%	1.11%	8.27%
Active Certificates	1.44%	3.28%	-8.13%

	NV: Nuclear Relief Valve		MO: Nuclear Material		OWN: Nuclear Owner	
	Both	**Only Nuclear**	**Both**	**Only Nuclear**	**Both**	**Only Nuclear**
Fraction of Total	2.14%	0.85%	1.53%	20.06%	0.00%	0.85%
Active Certificates	85.71%	100.00%	80.00%	78.87%	NA	33.33%
Avg Issuance Date	2006-06-30	2011-04-29	2010-10-01	2010-11-12	NA	2012-09-07

	Difference Between the Both Group and the Only Nuclear Group		
Fraction of Total	1.29%	-18.53%	-0.85%
Active Certificates	-14.29%	1.13%	NA

APPENDIX (H) CORRELATION MATRIX OF ALL ASME CERTIFICATION TYPES

Figure 28:
Correlation Matrix of All Components (Ibid supra 19)



APPENDIX (I) ASME BOILER AND PRESSURE VESSEL CODE COMPLIANCE

In addition to NQA-1, NRC Regulations require that SR pressure retaining components comply with Section III of the ASME Boiler and Pressure Vessel (BPV) Code[105]. These requirements apply to large power reactors, small modular reactors (SMR), micro-reactors, and advanced reactors. ASME BPV Code requirements are extended to the pressure retaining portions of SR SSC fluid systems for the following distinct Classes:

- Class 1: Reactor coolant pressure boundary (RCPB);
- Class 2: Fluid systems that interface with the RCPB, such as ECCS and component cooling; and
- Class 3: Fluid systems that do not directly interface with the RCPB, such as essential cooling and diesel generator cooling systems.

The Code specifies the required margins to the critical buckling strength for nuclear component primary membrane and bending moments, as a function of NRC and ASME required load combinations. These load combinations include normal operating pressure, thermal stress, post-accident, weight, and seismic stresses[106]. Beginning in 1963, ASME issued Certifications ("N-Stamps") to manufacturers of these three nuclear Classes of pressure retaining systems as compliant with the Code. Table 4 lists the ASME Code compliance Certifications for these nuclear-grade fluid systems.

ASME also established Certifications for the manufacture and installation of industrial grade boilers and fluid retaining systems. These Code requirements can be found in ASME BPV

Sections I, II, and IV. These non-nuclear Certifications include:

- S: Power Boilers
- A: Assembly of Power Boilers
- PP: Pressure Piping
- E: Electric Boilers
- PRT: Parts Fabrication.

[105] First mandated by the NRC in 1963, ASME BPVC, Section III, "Rules for Constructions of Nuclear Facility Components-Subsection NCA-General Requirements for Division 1 and Division 2,"(BPVC.III.NCA – 2023), Required by 10CFR50.55a (Ibid 9).

[106] Seismic stress, operational bases earthquake, and safe shutdown earthquake, defined by 10 CFR 100.

Table 26:
ASME BPV (Section III) Certifications for SR Pressure Retiming SSCs

Stamp		Stamp	
N	Pressure vessels, pumps, valves, piping systems, storage tanks, core support structures, concrete containments, and transport packaging.	**G**	Design of graphite or composite core components and assemblies
NA	Field installation and shop assembly of all items.	**OWN**	Nuclear power plant owner
NPT	Parts, appurtenances, welded tubular products, and piping subassemblies	**GC**	Graphite or composite core components and assemblies
NS	Supports	**NV**	Pressure relief valves
N3	Transportation containments and storage containments		

APPENDIX (J) SAFETY-RELATED COMPONENT COMPLEXITY

The specialization of large SR components is readily apparent. Reactor vessels and internals; steam generators; containment cooling and venting systems; reactor and reactivity control systems; and ECCS heat exchangers all have complex manufacturing processes. However, smaller, typical industrial SR components may also have less apparent specialized attributes. For example, most domestic power reactors use a SR steam driven feedwater pump. These steam turbines were provided by an NQA-1 vendor[107]. At a Midwest power reactor, the utility replaced the Inconel governor valve stem due to pitting. The utility decided to save money by using an "industrial-grade" replacement part. However, over the next year, the turbine failed multiple times due to overspeed. These failures were classified by the NRC as "safety system functional failures." The NRC investigation identified that the original NQA-1 vendor used a proprietary heat treatment to prevent the stem from thermally expanding, preventing the turbine overspeed trips. Another example involved motor operators for valves. The vendor[108] supplied SR operators to all U.S. nuclear plants (figure 2) and industrial grade operators to most large non-nuclear facilities. These operators use limit and torque switches to control the range of the valve stroke. Many failures of ECCs occurred due to the lack of adequate QA associated with the replacement of these switches. Another example involved flow transmitters. The NQA-1 vendor[109] supplied these transmitters to most of the U.S. nuclear fleet and many industrial facilities.

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[107] Terry Turbine Provide almost all the domestic SR turbine-drive auxiliary feedwater and reactor core isolation cooling pump turbines (https://www.osti.gov/servlets/purl/1529465).

[108] Limitorque (https://www.framatome.com/solutions-portfolio/docs/default-source/default-document-library/product-sheets/a0964-p-us-g-en-401-12-21-limitorque.pdf?sfvrsn=85a6da4e_0).

[109] Rosemount flow and pressure transmitters.

A utility replaced the transmitter seals with an industrial-grade component. Unknown to the licensee, these replacement seals were not qualified for the harsh post-accident environment that the SR transmitters were qualified for. The licensee's actions resulted in a failure of these transmitters, rendering the ECCS inoperable for an extended period.

Control of Structures, Systems, and Components Classification

NRC Rules[110] require each licensee to maintain a list (Q-List) of all SR, important to safety, and seismically qualified SSCs[111]. The "Q-List" is used to determine the QA requirements for procurement, design, storage, installation, maintenance, and testing of these components.

APPENDIX (K) SELECTION BIAS DISCUSSION

The regression results are treated as being representative of small nuclear component manufacturing in the U.S. It is assumed that the supply function of all small components can be aggregated, since the manufacturing equipment can be used to produce a range of component types, especially over the long run. As such, the difference in distribution between non-nuclear certificates and ASME N-cert data captures the nuclear industries unique manufacturing considerations.

To some extent the market must be aggregated as each nuclear component would have a highly limited data set. There may be only one "reactor vessel internal lifting ring" produced in the last 20 years, but there were multiple pressure containing parts produced in that time span. Because of this, aggregating to the "small component" level is considered the most insightful category.

However, this raises concerns about the aggregation process, and consequently selection bias. ASME N-cert data is limited to SR pressure containing components, and not all these components are ASME certified, having been produced using independent certification. Where small pressure-related components production firms respond significantly differently than other firms, the results could be biased.

Unfortunately, there is not sufficient data to perform a correction method such as an Inverse Propensity Weight Treatment Weighting (IPTW) regression. As a back of the envelop model justification, the available data on manufacturing firms is used.

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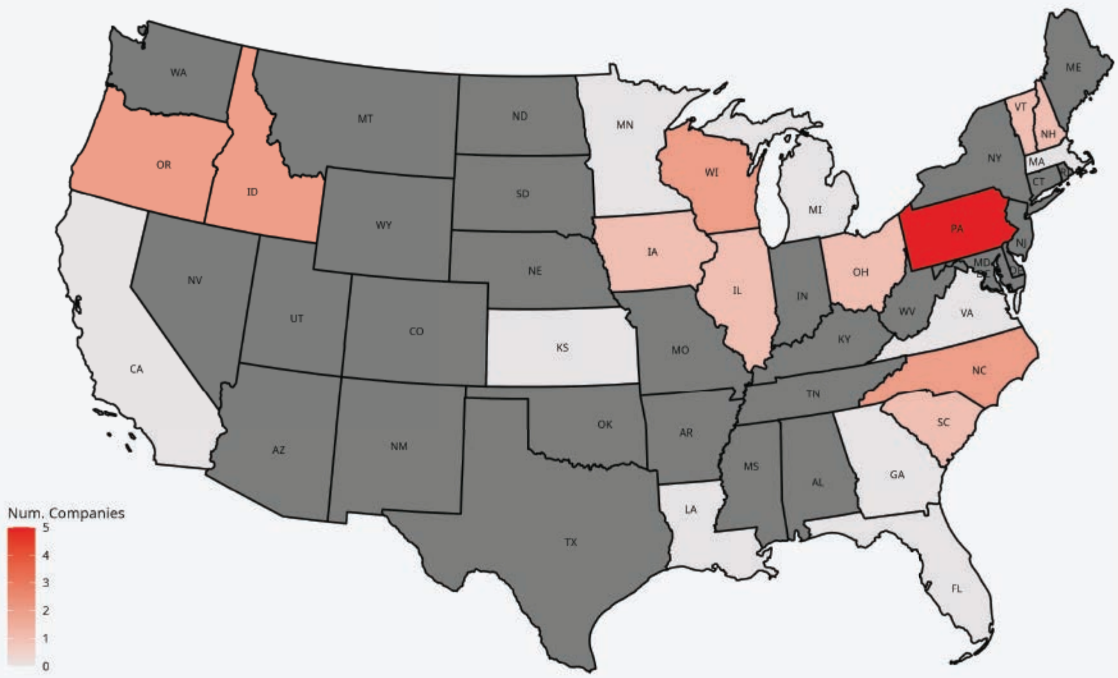
[110] Appendix B to Part 50—Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants, II. Quality Assurance Program (https://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-appb.html).

[111] EPRI, "Guideline for the Utilization of Commercial Grade Items in Nuclear Safety Related Applications 10 CFR 50, Appendix B, Criterion II, "Quality Assurance Program" (https://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-appb.html).

While no new additions to the U.S. nuclear power fleet were made for three decades, there were recent additions from the Vogtle 3 & 4 units which began construction in 2012 and started operating in 2023. A data set of the companies that produced components for these units was collected (Department of Energy, 2022). Then the ASME data set was searched to identify which of these companies matches a firm with an ASME certificate. The two groups are not directly comparable, as a single company may acquire multiple N-certificates. Further the Vogtle supply chain only captures a snapshot of active nuclear firms, whereas the year fixed effects model using the ASME dataset allows for yearly trends to be captured. Nevertheless, the potential bias from aggregation can be informed by comparing the two.

The map provided in Figure 27 plots the number of companies that are in the AP1000 data set but are not in the ASME certificate data set. This can be compared to Figure 13 in Section 3.5 which plots the ASME N-cert locations. The ASME data set captures more companies, because it includes both potential producers (are certified but did not sell to Vogtle) and all historic production.

Figure 29:
Location of AP1000 Suppliers Not in ASME Data Set (Department of Energy, 2022)



Some states were fully captured by the ASME data set such as Kansas, California, and Virgina. Pennsylvania has by far the most missing companies, which is a steel heavy state. It is likely that the small components aggregation assumption skews with component size. Parts that are not classified as “large” but tend to be larger are more likely to be constructed in States like Pennsylvania and Wisconsin that produce larger steel assemblies. The top five states for steel production are Indiana 26%, Ohio 12%, Michigan 5%, and Pennsylvania 5% (*Tuck, 2021*). While this does not fully explain the regional variation, all these states except Michigan have at least one missing company.

While this is a concern, it is of note that ASME N-cert data does exist in each of these States. It is theoretically acceptable to have missing data so long as that data is proportional to the observed data set. Also, to identify components that can be produced in Wyoming, weighing smaller non-steel components more heavily is a minor issue. This more accurately matches the forms of manufacturing found in the State.

One point that alleviates concern of selection bias is that there are at least some data points in states that are missing data. For example, two nuclear manufacturing companies supplied components to the Vogtle unit III or IV from Oregon and one of these had an ASME certificate.

A simple Poisson model was used to test for bias. In the model the number of companies supplying AP1000 parts was estimated, using the number of nuclear N-certs, and the number of non-nuclear ASME certificates ever acquired in a state. Three models were run, the first predicts the total number of AP1000 suppliers in a state, the second predicts the number of AP1000 suppliers in a state that *do not* have an ASME certificate, and the final model predicts the number of AP1000 suppliers that *do* have a ASME certificate. The results are presented in *Table 27.*

Table 27:
Poisson Model Comparison of Available and Missing Nuclear Suppliers

Dependent Variables	**Number of AP1000 Suppliers**	**Number of AP1000 Suppliers without N-Cert**	**Number of AP1000 Suppliers with N-Cert**
Model	**(1)**	**(2)**	**(3)**
Variables			
Constant	-1.222*** (0.2922)	-2.054*** (0.4382)	-1.786*** (0.3929)
Number of N-Cert. in a state	0.0965*** (0.0176)	0.0919*** (0.0267)	0.1008*** (0.0235)
Number of non-nuclear ASME Cert. in a state	5.03×10^{-5} (0.0008)	0.0005 (0.0011)	-0.0004 (0.0013)
Fit Statistics			
Observations	50	50	50
Squared Correlation	0.27441	0.19629	0.18415
Pseudo R^2	0.22510	0.16254	0.1837
BIC	111.04	74.753	84.692

*IID standard-errors in parentheses | Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

The results do not provide evidence of the existence of selection bias. The coefficient of "Number of N-Cert. in a state" is the variable of interest. This coefficient is nearly identical between model (2) predicting the number of AP1000 suppliers *missing* from the ASME data set, and model (3) predicting the number of AP1000 suppliers *in* the ASME data set. If there is a notable selection effect where the behavior of companies in the data set deviate from the unobserved AP1000 supplying firms, the coefficients should differ. The difference between these model coefficients is 8.17%, a z-test of the two N-cert coefficients cannot reject the null hypothesis that they are identical with a P-value of 0.79 (*Clogg et al., 1995*). This suggests that any selection effect at the firm level is minor, and the model can be applied.

To conceptualize what components are more heavily weighted in the model, this data is grouped by component type. *Table 28* lists the components supplied for the Vogtle units from a U.S. company and the percentage of that component supplied by a company in the ASME data set. Overall 55.9 percent of U.S. companies in the AP1000 supply chain were linked to a company with an ASME certificate.

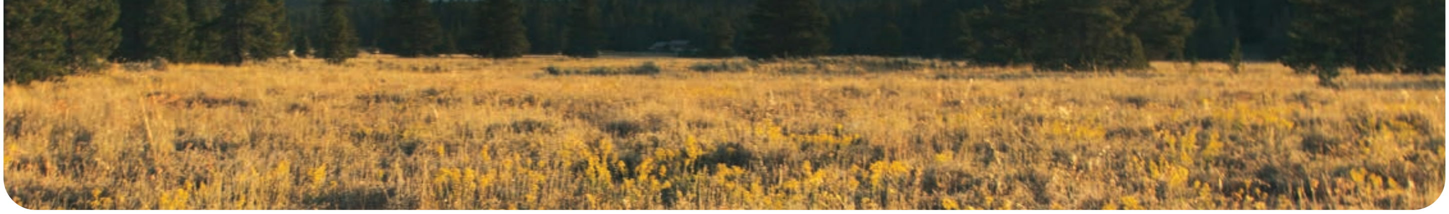
Any bias from missing data is skewed away from the components with 0% overlap. The location of companies producing cranes, batteries, and building panels are not fully captured by the data set. There is a focus on the firm availability rather than linking the N-cert to a particular component. For example, if the company providing the "integrated head packing" does not acquire a N-cert for this component yet acquires one for another part the results are still informative. In the short run, the component output is a Leontief production function. The ratio of components must remain constant. The firm's percentage increase in N-cert associated components will match the percentage increase of all other components.

This evidence affects the interpretation of the certification data. In the most restrictive interpretation, the models predict the certification rate of small safety related pressure containing components. However, based on some economic assumptions, this can be applied more broadly to small components, which have similar firm structures as pressure vessels. With this caveat in mind a conservative interpretation can be made.

Table 28:

Ratio of Vogtle U.S. Supplied Components Produced by Companies with an ASME N-cert (Department of Energy, 2022)

Component	Percent of Companies with N-cert
Automatic Depressurization System	100%
Squib Valves	100%
Class 1E Switchgear	100%
Control Rod Drive mechanisms	100%
Degasifiers	100%
Fuel Assemblies	100%
Instrumentation Valves	100%
Integrated Head Package	100%
Reactor Coolant Loop Piping	100%
Reactor Coolant Pumps	100%
Reactor Vessel Flowskirt	100%
Reactor Vessel Internal Lifting Rig	100%
Spend Resin Tank	100%
Steam Generator Recirculation and	100%
Drain Pumps	100%
Valves	57%
AP1000 Modules	50%
Class 1E Batteries	0%
Cranes	0%
Liquid Ring Vacuum Pump	0%
Radiation Monitoring Systems	0%
Recirculation Heaters	0%
Shield Building Panels	0%
Solenoid Valves	0%
Tank Demineralizers	0%
Unit Auxiliary Transformers	0%
Variable Frequency Drives	0%



APPENDIX (L) POLLUTION OUTPUT PREDICTED FROM NUCLEAR COMPONENT MANUFACTURING GROWTH

Table 29:
IMPLAN Environmental Impact Assessment

Output	Units	Mid-High Demand	High Demand
Commercial Non-Hazardous Waste Excluding Construction Activities	kg	6,720,989	23,302,477
Commercial Non-Hazardous Waste from Construction Activities	kg	727,207	2,549,841
Commercial RCRA Defined Hazardous Waste	kg	220,076	745,862
Criteria and Hazardous Air Emissions	kg	607,601	2,119,528
Greenhouse Gases	kg	109,923,829	380,029,735
Land Use	m2*a	20,304,904	72,201,518
Mineral Extraction	kg	47,423,324	154,298,873
Mineral Extraction	MJ	308,060	995,794
Nitrogen and Phosphorous Releases from Agriculture	kg	724	2,594
Pesticide Releases	kg	45	160
Point Source Industrial Releases to Ground	kg	1,511	5,260
Point Source Releases to Water	kBq	11	39
Point Source Releases to Water	kg	127,651	447,536
Water Withdrawals	kg	16,911,248,661	59,197,511,725

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