A fracking disappointment: The sociodemographic impacts of shale gas extraction in rural Pennsylvania and New York

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Abstract

Energy extraction is often touted as an antidote to rural decay in amenity-rich areas. However, to what extent does energy development truly benefit rural communities? In 2008, shale gas extraction through "fracking" began to dominate the landscape of rural Pennsylvania, with policymakers highlighting its positive socioeconomic effects for local communities. Despite sharing vast natural gas deposits, neighboring New York implemented a moratorium on fracking in 2008 and officially banned the practice in 2014. Using New York and Pennsylvania's differential approaches, this paper employs a synthetic control method to study fracking's local impact on population and socio-economic changes. While the analysis reveals a statistically significant population response to fracking with county-specific heterogeneity, the results underscore how fracking failed to translate into the touted demographic and economic boost for rural Pennsylvania. Thus, this analysis concludes that despite politicians', government agencies', and industry insiders' ambitious promises, in the context of population growth and socio-political advancement, the 2008 fracking boom was a bust.

1. Introduction

From the coal mines to the oil fields, amenity-rich rural areas are historically promised to benefit from their valuable resource endowments. Around 2008, the emergence of a new extractive industry—the so-called "fracking" industry—was no different, throwing a potential life-line to energy-rich rural areas experiencing trends of depopulation and economic uncertainty. Improvements to hydraulic fracking ("fracking") engineering and favorable market conditions enabled fossil fuel conglomerates to access and profit from immense amounts of valuable natural gas trapped in underground shale rock (EIA, 2017; EIA, 2011; Rapier, 2017; Soeder & Kappel, 2009; Falchek, 2008; U.S. Department of Energy, 2009).

The economic stimulus brought by the booming fracking industry through new jobs, spillovers into ancillary industries, and lease/royalty payments to families looked to not only attract new residents to affected communities, but also public and private investment from governments and companies looking to capitalize on the economic revival of energy-rich rural areas (Corbett, 2014). Moreover, as a result of this newfound economic stimulus, current residents who previously perceived their economic prospects at home to be limited should also, in theory, be more inclined to remain—stymying existing population decline.

Population changes are acutely important to study due to their impact on a region's political clout and socio-economic circumstances. While population dynamics are universally considered a key factor in understanding the long-term socioeconomic trajectory of places, in the U.S. context, population change have broader implications since it can influence political factors such as the apportionment of seats in the U.S. House of Representatives, the drawing of districts for the state legislature, as well as electoral college votes and impacts on presidential elections (Hotchkiss & Phelan, 2017). Socio-economically, population can also dictate the amount of federal funding a locale receives, local public school funding, infrastructure investment, the number of available career opportunities, the amount of local spending, an area's attractiveness and competitiveness for talent, and healthcare investment and availability of services (e.g., cardiovascular specialists, dermatologists, podiatrists) (Hotchkiss & Phelan, 2017).

Yet, there is a paucity of literature studying the impact of fracking on population, despite the importance of population in contributing to a region's overall health and well-being and the potential for fracking to reverse rural depopulation trends. Specifically, other important subjects have been the focus of fracking literature—including its influence on economic opportunities (e.g., Weinstein and Partridge, 2011; Cosgrove, LaFave, Dissanayake, and Donihue, 2015), the housing market (e.g., Muehlenbachs, Spiller, and Timmins, 2015; Bennett and Loomis, 2015; Williamson and Kolb, 2011), and health and the environment (e.g., Moss, Coram, and Blashki, 2013; Boslett and Hill, 2021). However, limited studies have spotlighted the demographic implications of fracking for local communities.

This paper aims to address these gaps by exploiting the natural experiment arising from Pennsylvania and New York's differing approaches to fracking policy, with New York outlawing the practice and Pennsylvania embracing it—evolving into one of the most prolific natural gas producing regions in the U.S. (EIA, 2021; Kaplan, 2014). This research features a synthetic control analysis to discern how the 2008 fracking boom impacted population trends in some of the most productive fracking counties in Pennsylvania compared to socio-demographically similar counties in New York, where fracking failed to materialize. Second, this paper further examines the socio-political impacts of such population shifts, focusing specifically on Congressional reapportionment, political representation, and governmental distribution of fracking-related taxes.

Overall, this research contributes to the existing literature in four main ways. First, this paper employs a novel approach to estimating population change from the fracking boom—the synthetic control method—with a unique focus on the individual-county level. The synthetic control model wields several empirical advantages over other relevant tools common in the literature, such as difference-in-differences (e.g., Mayer et al. (2017)). Second, of the limited literature specifically focusing on the socio-demographic consequences of fracking, many are conducted in, or use data from, the early years of the fracking boom—limiting concerned audiences' and stakeholders' (e.g., local governments) abilities to understand the long-term implications of natural gas extraction. Additionally, few studies concentrate on changes in population resulting from fracking solely in northeastern Pennsylvania—one of the most significant natural gas producing regions in the U.S. (Bushman & Flaugh, 2021; EIA, 2021). Lastly, this research goes a step beyond traditional analyses which ignore the socio-political implications of shifting populations, such as Congressional representation and government funding—both of which are critical to the survival of weakened rural communities. Ultimately, this analysis will facilitate an improved understanding of fracking and its significance for rural communities, across the U.S. and beyond.

The remainder is structured as follows. Section two explores the existing literature intersecting population and fracking. Section three describes the main data sources and the empirical methods adopted in the analysis. Section four presents the results on the causal impact of fracking on population change, complementing them with a discussion of the potential drivers of population changes and their broad implications for rural communities in section five. Lastly, a summary of the paper and its key findings are outlined in the conclusion, ending with final recommendations for future research.

2. A Review of the Literature

Due to the growing prominence of the natural gas industry, the debate over natural gas as a bridge fuel to renewable energy sources, and the emphasis placed by worldwide governments on energy independence, fracking has evolved into a compelling, yet contentious, subject across various disciplines. Despite this growing interest, the paucity and shortcomings of existing literature provide additional motivation for up-to-date, multidimensional research while underpinning the need for additional studies examining the relationship between fracking and population dynamics on a more micro-level, like in northeastern Pennsylvania—a posterchild for the many global rural communities disproportionately impacted by shale gas development and the corresponding migratory impacts of the oil and gas industry's presence (Rajbhandari et al., 2020).

2.1: The Self-Serving Depopulation Cycle

According to the U.S. Department of Agriculture, 2017 marked the first time rural areas in the United States experienced an overall natural decrease, with deaths surpassing births (Davis, Rupasingha, Cromartie, & Sanders, 2022, p.4). Johnson and Lichter (2019, p.24) highlight how the outmigration of reproductive-age youth works in tandem with natural decrease to perpetuate a spiral of rural depopulation. Specifically, older adults remaining in rural areas—or migrating to rural areas for retirement—drives an increase in deaths while the hollowing out of youth populations spurs a decrease in births (Carr & Kefalas, 2010; Davis et al., 2022; Johnson & Lichter, 2019).

The downstream effects of these trends result in widespread economic consequences, particularly a tightened labor supply. In particular, the proportion of working-age adults (i.e., ages 18-64) is smaller in rural counties than urban counties (Davis et al., 2022). An absence of workers contributes to shrinking tax bases for rural communities to invest in existing infrastructure and the development of amenities to attract younger families and workers (Carr & Kefalas, 2010). Indeed, among other factors, underlying these demographic trends is the relative scarcity of opportunities and well-paying jobs (Susquehanna County, 2003). However, rural communities' abilities to invest in themselves and become appealing destinations for families and young adults is limited by their existing demographic declines, which preclude the cultivation of new, attractive job prospects, modern infrastructure development, and appealing amenities such as proximity to supermarkets and medical care (Dobis, Krumel Jr., Cromartie, Conley, Sanders, & Ortiz, 2021).

2.2: Population Dynamics and Fracking

The emergence of a new extractive industry—fracking—promised to put a stop to this self-serving cycle of depopulation, shrinking job opportunities and tax bases, and loss of attractive amenities. While current academic discourse has examined the trends and models of rural demography more broadly, there remains a dearth of scholarship exploring whether rural population is indeed impacted by the presence of the fracking industry.

One of the few papers specifically focusing on the relationship between population dynamics and fracking is an exploratory, policy-oriented report by the Center for Rural Pennsylvania. The authors found an opaque relationship between fracking and population changes (McLaughlin et al., 2014b, p.1). However, the researchers do not conduct robust statistical analyses to reach their conclusions, instead relying on basic mathematical computations (McLaughlin et al., 2014b, p.6). Moreover, the limited time-frame included in McLaughlin et al.'s (2014b) analysis prevents the authors from evaluating the long-term impact of natural gas exploration on population trends. Lastly, the analysis fails to capture the complete breadth of population changes due to the transient nature of the fracking workforce, particularly in the early years of development (McLaughlin et al., 2014b, p.1, 20).

Another subset of relevant literature examines the relationship between population, migration, and fracking. Research by Mayer, Malin, and Olson-Hazboun (2017) estimated the impact of fracking on rural brain drain across the United States, concluding that fracking does not impact in-migration patterns nor retain an area's human capital (Mayer et al., 2017, p.219, 234). However, Mayer et al.'s (2017) final year of study was 2010; this limited scope of research is problematic due to the fracking boom's initiation in 2008, hindering scholars' capacity to capture the true long-term socio-demographic trends resulting from the fracking boom (Mayer et al., 2017, p.234).

Munasib and Rickman (2015) employ a synthetic control model to estimate the economic and population effects of fracking in the United States (Munasib & Rickman, 2015, p.4). Ultimately, Munasib and Rickman's (2015) analysis did not find substantial changes to population as a result of fracking in Pennsylvania. However, similar to previous research, the use of a constrained time-frame of study (2001-2011) and reliance on an early intervention year (2006) hinder the ability to evaluate the true population changes due to fracking (Munasib & Rickman, 2015). In a parallel paper, Huang and Etienne (2021) also employed a synthetic control analysis examining fracking's economic and population impacts with a focus on Pennsylvania, West Virginia, and Ohio (Huang & Etienne, 2021, p.1449). After analyzing each state's most productive counties, the authors concluded that, in Pennsylvania specifically, fracking adversely impacted regions' population growth (Huang & Etienne, 2021, p.1456, 1457, 1469). However, while efficient, the authors' aggregation techniques fail to capture the nuanced effects fracking may have on individual counties.

Additional research from Wilson (2021) finds that information exposure from news media regarding the employment benefits of fracking generally promotes migration to fracking regions highlighted by news coverage—suggesting that receiving information highlighting the prospects of jobs in the fracking industry induces individuals to migrate to areas with employment opportunities in the field. This builds upon Wilson's (2020) prior study exploring the relationship between fracking and migration, finding "...that fracking increased migration to impacted areas, but there is significant heterogeneity across both demographics and regions" (Wilson, 2020, p.918). However, while both studies scrutinized population changes related to fracking, neither piece specifically focused on the rural nature of receiving regions and the implications of fluctuating population numbers, including Congressional representation, political clout, and government investment (Hotchkiss & Phelan, 2017; U.S. Census Bureau, 2021(c)(e); Wilson, 2020; Wilson, 2021).

3. Data and Methods

3.1: Data Sources

This analysis employs population data collected between the years 2000 and 2020 from the United States Census Bureau. The year 2008 serves as the treatment year, as it marked the inceptive, large-scale growth in newly developed methods of natural gas production in Pennsylvania (i.e., the "fracking boom") and was the period in which producers took advantage of favorable regulatory conditions (in Pennsylvania) and broader market tailwinds (Rapier, 2017). Since the fracking boom initiated in 2008, using a twenty-year time span from 2000 to 2020 offers sufficient numbers of pre-treatment (8) and post-treatment (13) periods to discern the overall effects of fracking on population.

The Census Bureau is Constitutionally tasked with enumerating the U.S. population every ten years (U.S. Census Bureau, 2021(a)(c)(d); U.S. Congress, n.d.; U.S. Constitution, 1787). Consequently, actual Census counts are only available for three (2000, 2010, and 2020) of the data's twenty years. However, to ensure consistency, this analysis relies solely on population estimates collected from the Census Bureau's "County Intercensal" and "Vintage 2020" datasets, which are available in ten-year batches: 2000 to 2010 and 2010 to 2020, respectively[1] (U.S. Census Bureau Intercensal Dataset, 2021; U.S. Census Bureau Vintage 2020 Dataset, 2022). Indeed, a weakness of the data is the employment of estimates rather than actual counts, potentially decreasing their overall accuracy. However, the Bureau's estimation techniques are produced using mathematical models which may help lessen the overall discrepancy between actual and estimated numbers (U.S. Census Bureau, 2021b, p.1; U.S. Census Bureau, 2012, p.2). Additionally, previous "vintage" population estimates have proven to mirror actual population counts with high rates of accuracy (U.S. Census Bureau, 2021b, p.1). Moreover, "vintage" population estimates are also trusted by various institutions "for federal funding allocations, as controls for major surveys including the Current Population Survey and the American Community Survey, for community development, to aid business planning, and as denominators for statistical rates" (U.S. Census Bureau, 2021b, p.1).

[1] As the Census Bureau's "County Intercensal" and "Vintage 2020" datasets each contain 2010, I use population data from the "County Intercensal" dataset for 2010. However, there should not be a substantive difference in my results stemming from the use of the "County Intercensal" dataset as opposed to the "Vintage 2020" dataset.

U.S. Census Bureau Intercensal Dataset. (2021, December 16). County Intercensal Datasets: 2000-2010. Retrieved June 28, 2022, from https://www.census.gov/data/datasets/time-series/demo/popest/intercensal-2000-2010-counties.html.
U.S. Census Bureau Vintage 2020 Dataset. (2022, January 27). County Population by Characteristics: 2010-2020. Retrieved June 28, 2022, from https://www.census.gov/programs-surveys/popest/technical-documentation/research/evaluation-estimates/2020-evaluation-estimates/2010s-county-detail.html.

3.2: Overall Methodology: Comparative Case Study; Research Question 1: What is the impact of the 2008 fracking boom on population in Pennsylvania?

Exploiting the natural experiment arising through the differential policy approaches of New York and Pennsylvania, the principle objective of this research is to use a comparative case study framework to estimate the impact of fracking ("treatment") on population in Pennsylvania ("outcome of interest"), with a focus on three of the most productive natural gas producing counties in the state—Bradford, Tioga, and Susquehanna (Figure 1)—relative to population outcomes in rural upstate New York counties, all of which ban fracking (Abadie, 2021, p.393; Cosgrove et al., 2015, p.27). This analysis also concentrates specifically on these three Pennsylvania counties due to their geographic proximity, demographic similarities, and population trends comparable to rural regions in upstate New York (see Graph 1 in Appendix for population trends of included counties between 2000 and 2020). The selection of these three Pennsylvania counties aligns with previous research studying the impacts of fracking, such as Cosgrove et al. (2015).

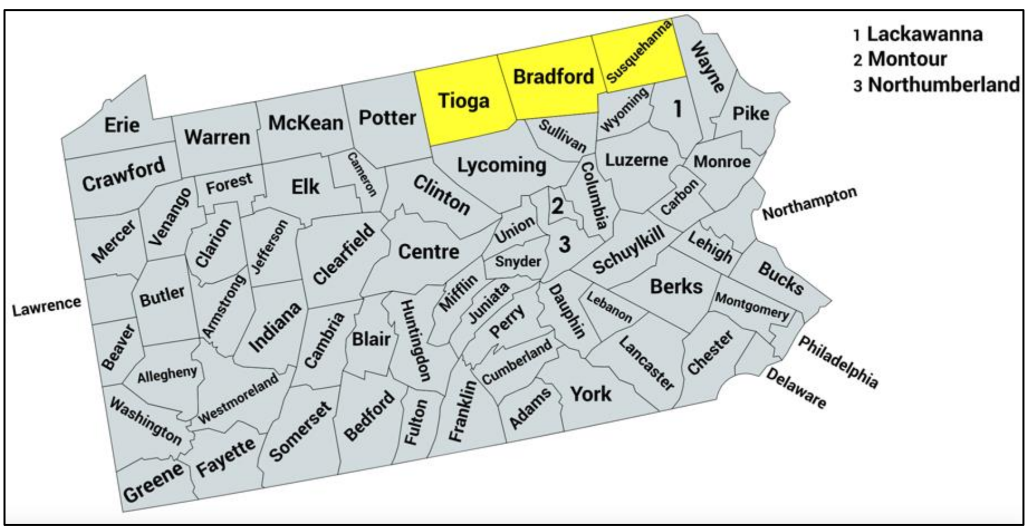

Figure 1: Selected Pennsylvania Counties (Bradford, Tioga, and Susquehanna); Photo Source: MapChart.net. **Color Required**

3.3: Synthetic Control Analysis

A common approach to estimating the impact of large economic shocks, such as energy development, on local communities is the Difference-in-Differences (DiD) method (Cosgrove et al., 2015; Mayer et al., 2017). While DiD analyses are useful econometric methods which help isolate the causal effect of a treatment—particularly when using aggregated data—they are imperfect in practice. Specifically, one of the central downsides of DiD approaches is the arbitrary selection of control units, which are based on apparent similarities between treatment and control units (Abadie, 2021, p.393; Cunningham, 2021).

The synthetic control method (SCM) attempts to correct for these shortcomings in comparative case studies by formalizing the selection of the comparison units using data-driven algorithmic selection parameters. In other words, SCMs employ inputted covariate data to allot weights to New York counties—also called the donor pool—to estimate the changes in population in individual treatment units (i.e., Susquehanna, Bradford, and Tioga Counties).

The covariates included in the analysis are: total and per-capita personal income, average yearly unemployment rate, and population broken down by gender, ethnicity, and age—specifically the age group of 15 to 19, a period when individuals are likely to make migration decisions and begin careers in the fracking industry (Schafft & Biddle, 2014). This paper conducts three separate synthetic control analyses, one for each county (Bradford, Susquehanna, and Tioga), using the same covariates between models.[*]

Overall, the SCM enhances this analysis in three aspects. First, the algorithm used to generate a counterfactual attenuates the arbitrary selection of control units common in the literature (Abadie, 2021; Cunningham, 2021). Second, unlike in regression-based models, the SCM enables researchers to see the weight each New York county is donating to the estimation of each Pennsylvania county. Lastly, unlike in a DiD analysis which examines changes in aggregate (i.e., all PA treatment counties and all NY control counties), through the SCM, changes in population among the three PA counties individually are able to be studied—allowing this analysis to capture potential intercounty heterogeneity in the population response to fracking.

*In order to obtain the most optimal results, the "nested" option is specified within the "synth" STATA package, which produces a better predicted model fit (Hainmueller et al., n.d.). Without the "nested" option specified, the resulting graphs suggest a poor model fit (i.e., the difference between the predicted and actual population values is large and the synthetic trends no longer follow Bradford, Susquehanna, and Tioga Counties' population trends in the pre-treatment) (Hainmueller et al., n.d.).

Hainmueller, J., Abadie, A., & Diamond, A. (n.d.). Help synth: Synth -- Synthetic control methods for comparative case studies. Retrieved June 29, 2022, from http://fmwww.bc.edu/RePEc/bocode/s/synth.html

3.4: Examining Impacts of Fracking-Induced Population Changes on Communities; Research Question 2: What are the resulting socio-political implications of population changes from the fracking boom?

The final portion of this analysis focuses on evaluating how fracking-induced population changes affect local communities in Pennsylvania. This paper specifically examines two areas of possible impacts that are both dependent upon population counts and can influence an area's ability to invest in its communities: (1) Congressional reapportionment and political clout and (2) amount of funding received from the Pennsylvania state government's collection of fees levied on fracking companies (Act 13 of 2012). Reapportionment effects are measured by qualitatively reviewing U.S. Census Bureau publications contained within its online "Congressional Apportionment" information section (U.S. Census Bureau, 2021e), as well as reports from popular media sources which analyze the impacts of changing Congressional maps and the subsequent political landscape for candidates vying to represent Bradford, Susquehanna, and Tioga Counties within the U.S. House of Representatives.

Funding data are employed from Pennsylvania government sources including the Pennsylvania Public Utility Commission and the state legislature to discern changes to population-based funding streams. Specifically, legal documents associated with Pennsylvania's Act 13 are analyzed to explore the funding formula underlying the disbursement of county funds, how the amount of funding fluctuates with population, and the discretionary purposes the funds are able to be used for under the purview of the law. Moreover, this paper employs Public Utility Commission data to obtain exact amounts of funding Bradford, Susquehanna, and Tioga Counties receive under Act 13's population-based funding formulas.

Together, these data from the U.S. Census Bureau, diverse news organizations, and state government sources offer reliable insights into the dynamic relationship between politics, population and funding, facilitating an exploration of the socio-political impacts of fracking-induced population shifts in Bradford, Susquehanna, and Tioga Counties through a critical yet objective lens.

4. Results

4.1: Synthetic Control

As previously mentioned, the SCM employs a data-driven algorithm to optimally weigh control units and construct a counterfactual—estimating how population would have changed in Bradford, Susquehanna, and Tioga Counties had fracking not materialized. Moreover, the SCM allows for a study of potential intercounty heterogeneity in population trends by scrutinizing the impact of fracking in each county individually, rather than in combined aggregate. Tables 1, 2, and 3 highlight the weights allocated to control units for each Pennsylvania county of interest.

Table 1: Synthetic Control Weights Selected for Bradford County, PA

County	Weight
Cattaraugus County, NY	0.001
Chautauqua County, NY	0.056
Herkimer County, NY	0.444
Tioga County, NY	0.471
Warren County, NY	0.028

"County" corresponds to the New York counties selected through the SCM to be control units based on inputted covariate data. "Weight" corresponds to the amount each New York county is donating to the estimation of Bradford County, PA.

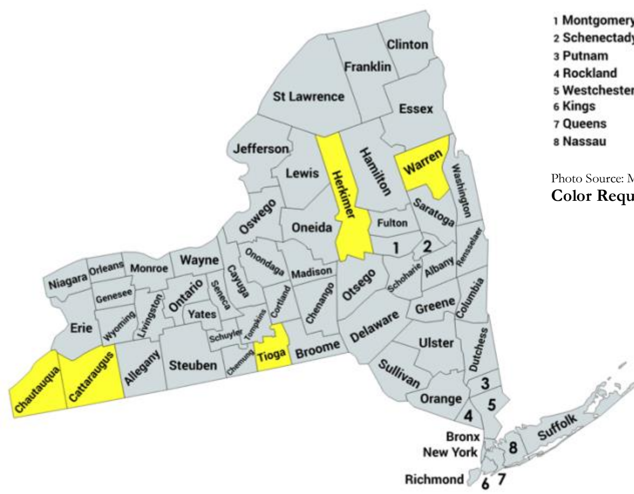

Photo Source: MapChart.net
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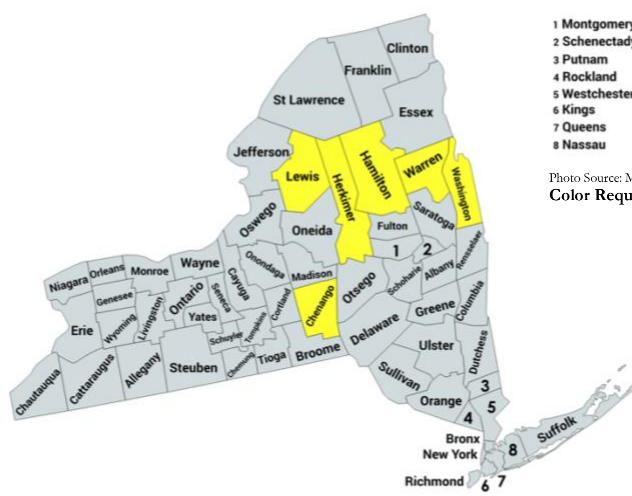
Table 2: Synthetic Control Weights Selected for Susquehanna County, PA

County	Weight*
Chenango County, NY	0.005
Hamilton County, NY	0.039
Herkimer County, NY	0.036
Lewis County, NY	0.498
Warren County, NY	0.220
Washington County, NY	0.201

"County" corresponds to the New York counties selected through the SCM to be control units based on inputted covariate data. "Weight" corresponds to the amount each New York county is donating to the estimation of Susquehanna County, PA.



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*Note: Weights are rounded and therefore do not add up to one in the table.

Table 3: Synthetic Control Weights Selected for Tioga County, PA

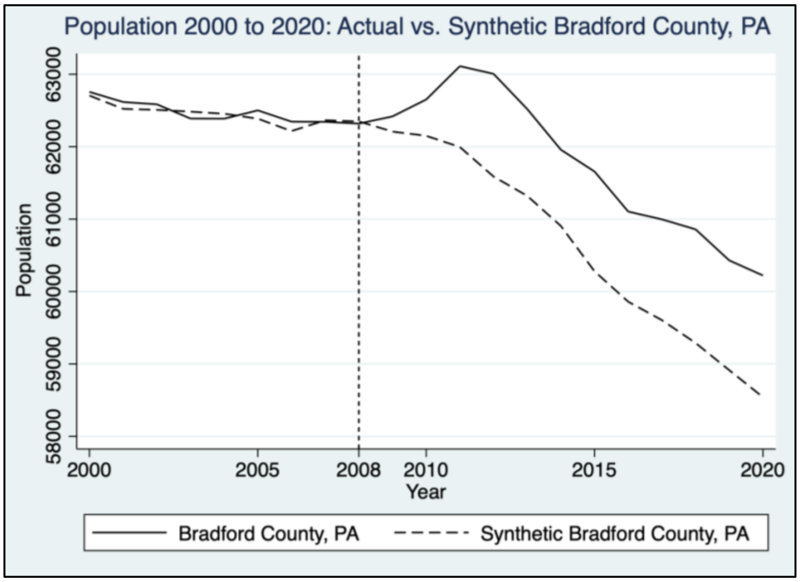
County	Weight
Allegany County, NY	0.223
Chenango County, NY	0.211
Oswego County, NY	0.069
Schuyler County, NY	0.217
Yates County, NY	0.280

"County" corresponds to the New York counties selected through the SCM to be control units based on inputted covariate data. "Weight" corresponds to the amount each New York county is donating to the estimation of Tioga County, PA.

4.2a: Successful Synthetic Control? Check of Pre-Treatment Alignment and Covariate Balancing

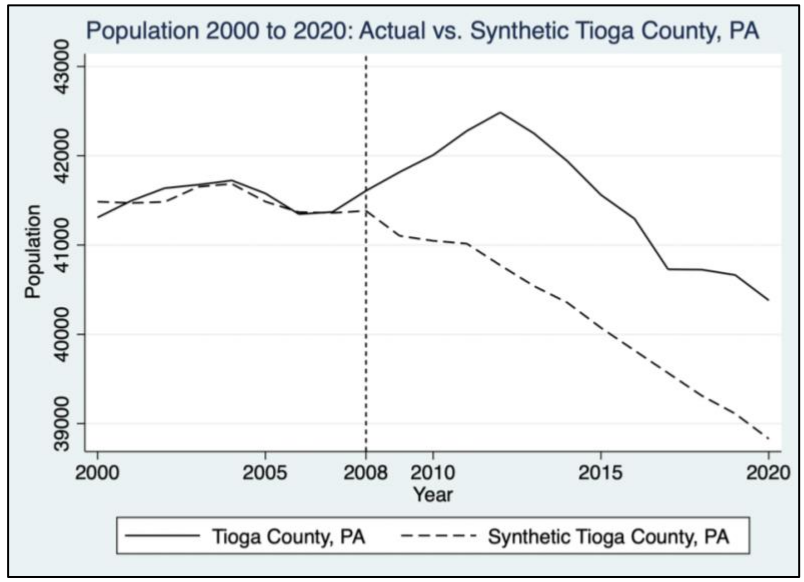
An important component of a successful synthetic control analysis is whether in the pre-treatment (i.e., before 2008), the weighted New York counties produce "a nearly identical time path" (Cunningham, 2021) to the Pennsylvania county of interest. Alignment of pre-treatment synthetic and actual trends indicates the SCM reasonably allocated weights to control counties and thus provided an appropriate counterfactual estimating how population would have changed in Bradford, Susquehanna, and Tioga Counties between 2008 and 2020 (i.e., post-treatment period) had the fracking boom not materialized. Ultimately, "if there is a causal effect, (the paths) diverge from (one) another post-treatment, but resemble each other pre-treatment" (Cunningham, 2021). Graphs 2, 3, and 4 demonstrate the synthetic and actual trends for each Pennsylvania county of study.

Another indicator of a successful synthetic control analysis is the matching of covariate (i.e., per-capita personal income, unemployment rate, etc.) values between the synthetic and actual groups in the pre-treatment (Abadie et al., 2010; Cunningham, 2021). Specifically, if the SCM produced optimized weights of control counties, then pre-treatment covariate values between the synthetic and actual groups should be similar (Abadie et al., 2010; Cunningham, 2021). Table 5 in the Appendix highlights the actual values for each covariate next to their synthetic values—both averaged over the pre-treatment period (2000 to 2007)—for each county in Pennsylvania.



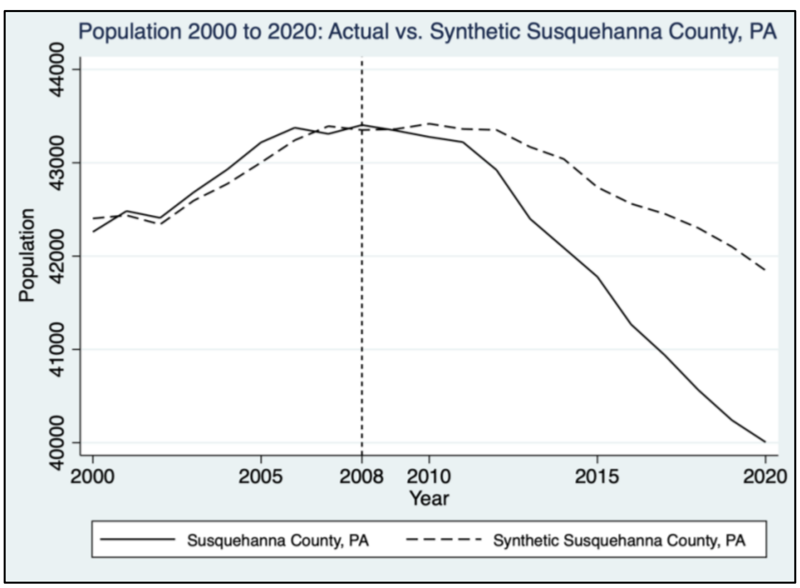
Graph 2: Actual vs. Synthetic Bradford County, PA

Solid line represents actual population trend in Bradford County, PA from 2000 to 2020, while the dotted line represents the estimated population trend derived from the "synthetically produced" Bradford County (see Table 1) from 2000 to 2020. The vertical dotted line at 2008 serves as the delineation between pre-fracking (2000-2007) and post-fracking (2008-2020) periods.



Graph 3: Actual vs. Synthetic Tioga County, PA

Solid line represents actual population trend in Tioga County, PA from 2000 to 2020, while the dotted line represents the estimated population trend derived from the "synthetically produced" Tioga County (see Table 3) from 2000 to 2020. The vertical dotted line at 2008 serves as the delineation between pre-fracking (2000-2007) and post-fracking (2008-2020) periods.



Graph 4: Actual vs. Synthetic Susquehanna County, PA

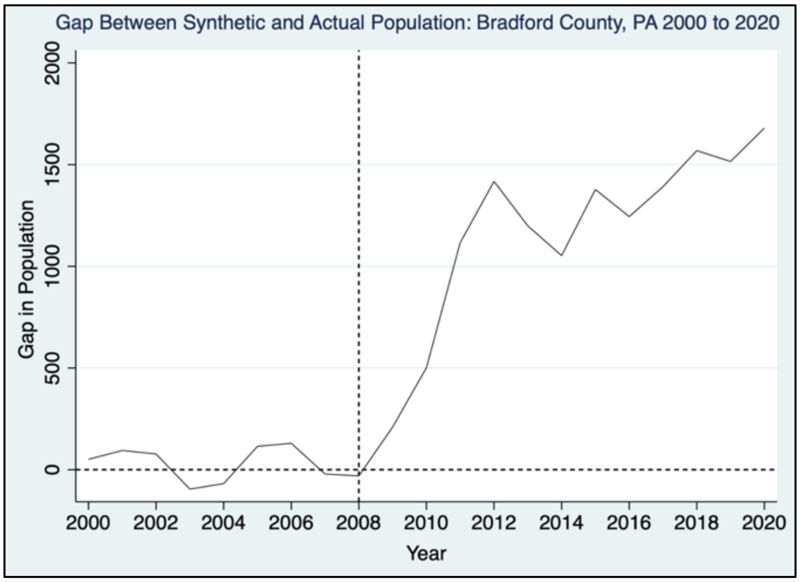
Solid line represents actual population trend in Susquehanna County, PA from 2000 to 2020, while the dotted line represents the estimated population trend derived from the "synthetically produced" Susquehanna County (see Table 2) from 2000 to 2020. The vertical dotted line at 2008 serves as the delineation between pre-fracking (2000-2007) and post-fracking (2008-2020) periods.

Graphs 2, 3, and 4 reveal that the synthetic population trends mirror the actual population trends for each county in Pennsylvania throughout the pre-treatment period. Moreover, most covariate values between the synthetically produced and actual counties match with a high level of accuracy in the pre-period (i.e., are "balanced"), shown in Table 5 in the Appendix. Graphical resemblance in the pre-treatment period coupled with balanced covariates between groups suggest that the SCM assigned fairly optimal weights to each county—shown in Tables 1, 2, and 3—and therefore offers a reasonable estimation of how population would have evolved in Bradford, Susquehanna, and Tioga Counties between 2008 and 2020 had there been no fracking (i.e., the counterfactual).

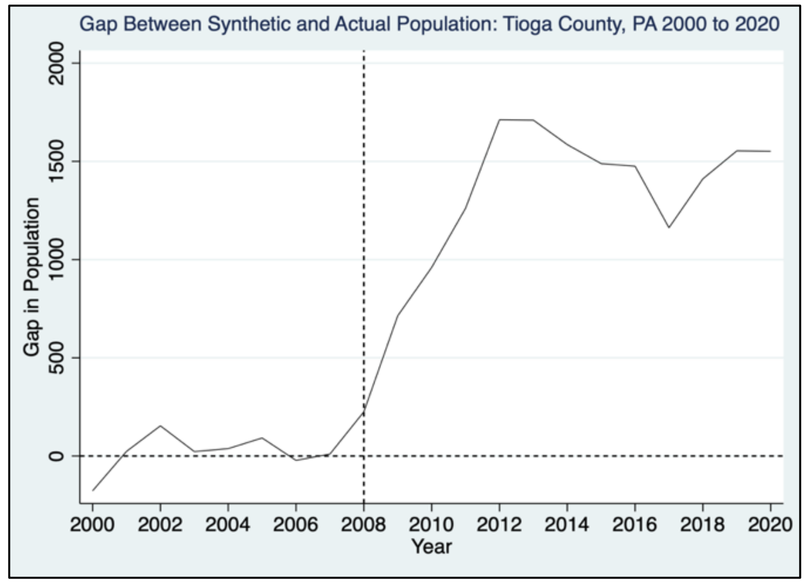
Moreover, with a sufficient number of pre-intervention periods (eight in this analysis, approximate to analogous literature, e.g., Munasib and Rickman, 2015) the "matching on preintervention outcomes" (Abadie et al., 2015, p.498) as illustrated in Graphs 2, 3, and 4, "helps control for unobserved factors and for the heterogeneity of the effect of the observed and unobserved factors on the outcome of interest" (Abadie et al., 2015, p.498). Specifically, concerns surrounding "the presence of unmeasured factors affecting the outcome variable (population)" (Abadie et al., 2015, p.498) are mitigated by the clear alignment of synthetic and actual trends in the pre-treatment period, since "only units that are alike in both observed and unobserved determinants of the outcome variable as well as in the effect of those determinants on the outcome variable should produce similar trajectories of the outcome variable over extended periods of time" (Abadie et al., 2015, p.498; Cunningham, 2021).

"Once it has been established that the unit representing the case of interest and the synthetic control unit have similar behavior over extended periods of time prior to the intervention (i.e., the alignment of synthetic and actual trends in the pre-treatment period), a discrepancy in the outcome variable following the intervention is interpreted as produced by the intervention itself" (Abadie et al., 2015, p.498). In other words, the overarching idea in synthetic controls that "only units that are alike on unobservables and observables would follow a similar trajectory pre-treatment" (Cunningham, 2021) is supported in this analysis by the clear alignment of actual and synthetic trends between 2000 and 2007 (pre-treatment) in Graphs 2, 3, and 4 above, and any divergence in trends after 2008 can be viewed as being caused by the intervention: fracking.

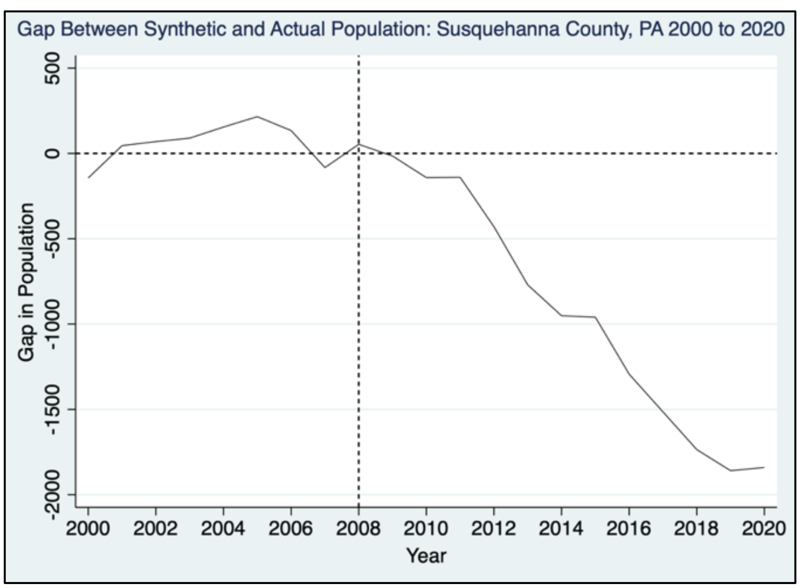
Hence, the impact of fracking on population is the variation between the actual and synthetic population trends in each county following fracking's initiation in 2008 (Abadie et al., 2010, p.500). Graphs 5, 6, and 7 depict this difference, where the data points represent the amount by which the actual population trend deviates from the synthetic trend (Abadie et al., 2010, p.500).



Graph 5: Bradford County Synthetic-Actual Population Gap. Line depicts the amount by which the actual population trend in Bradford County deviates from the synthetic population trend (difference between solid and dotted lines highlighted in Graph 2) between 2000 and 2020. The vertical dotted line at 2008 serves as the delineation between pre-fracking (2000-2007) and post-fracking (2008-2020) periods.



Graph 6: Tioga County Synthetic-Actual Population Gap. Line depicts the amount by which the actual population trend in Tioga County deviates from the synthetic population trend (difference between solid and dotted lines highlighted in Graph 3) between 2000 and 2020. The vertical dotted line at 2008 serves as the delineation between pre-fracking (2000-2007) and post-fracking (2008-2020) periods.



Graph 7: Susquehanna County Synthetic-Actual Population Gap. Line depicts the amount by which the actual population trend in Susquehanna County deviates from the synthetic population trend (difference between solid and dotted lines highlighted in Graph 4) between 2000 and 2020. The vertical dotted line at 2008 serves as the delineation between pre-fracking (2000-2007) and post-fracking (2008-2020) periods.

As shown in Graphs 2, 3, and 4—as well as 5, 6, and 7—following the fracking boom in 2008, the synthetic and actual post-period population trends appear to consistently diverge from each other over time. If fracking had no impact on population, the actual population trend should not differ from its synthetic complement. In other words, with no effect, the gap between actual and synthetic trends should be approximately 0 throughout the entire research period (2000 to 2020). However, such gaps hover around 0 only in the pre-treatment period (2000-2007), continually diverging throughout the post-treatment period (2008-2020), as demonstrated in Graphs 5, 6, and 7—signifying an effect of fracking on population in each county.

4.2b: Inference

Although these results suggest that fracking indeed impacted population in each county, it is unclear whether the difference in population between the synthetic counties and actual counties in the post-period is statistically significant. In order to decipher whether this divergence is significant, or occurred simply by chance, this analysis follows the methods of inference for synthetic controls outlined in Abadie et al. (2010) and Cunningham (2021).

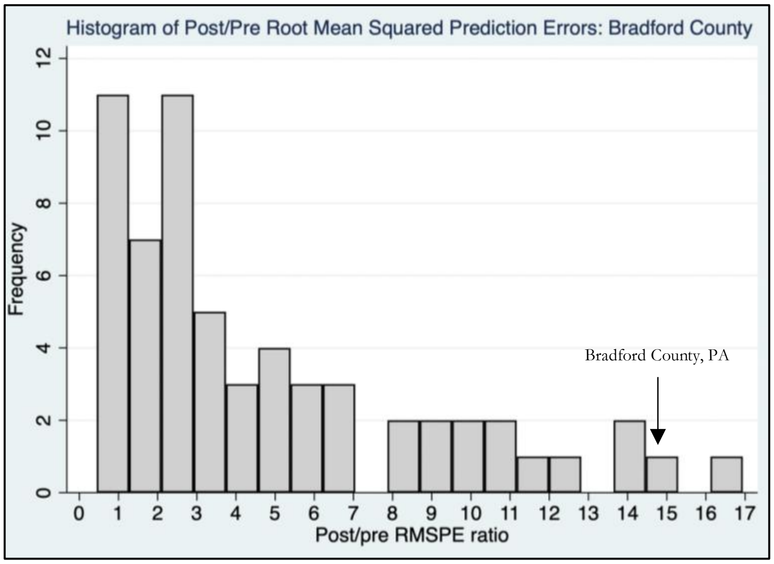
1. Iteratively apply the synthetic control method to each country/state in the donor pool and obtain a distribution of placebo effects.
2. Calculate the RMSPE for each placebo for the pre-treatment period:

$$RMSPE = \left(\frac{1}{T-T_0}\sum_{t=T_0+t}^{T}\left(Y_{1t}-\sum_{j=2}^{J+1}w_j^*Y_{jt}\right)^2\right)^{\frac{1}{2}}$$

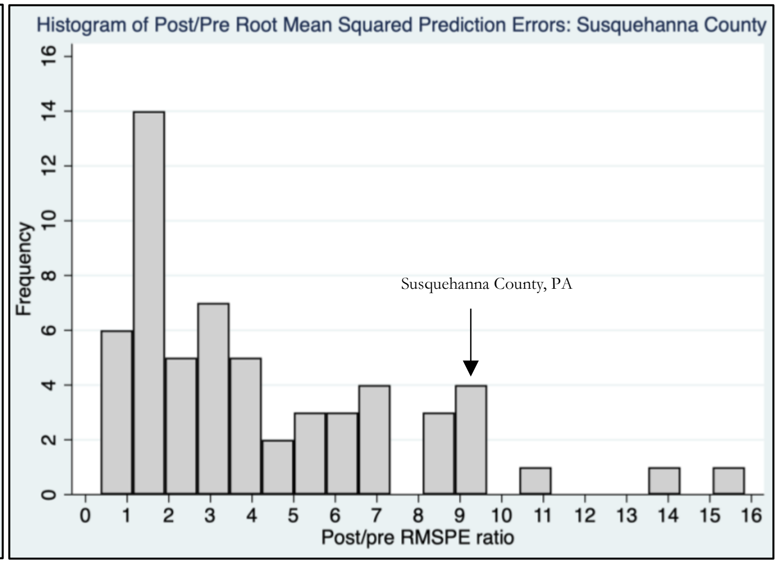
3. Calculate the RMSPE for each placebo for the post-treatment period (similar equation but for the post-treatment period).
4. Compute the ratio of the post- to pre-treatment RMSPE.
5. Sort this ratio in descending order from greatest to highest.
6. Calculate the treatment unit's ratio in the distribution as $p = \frac{RANK}{TOTAL}$.

Source: Cunningham (2021)

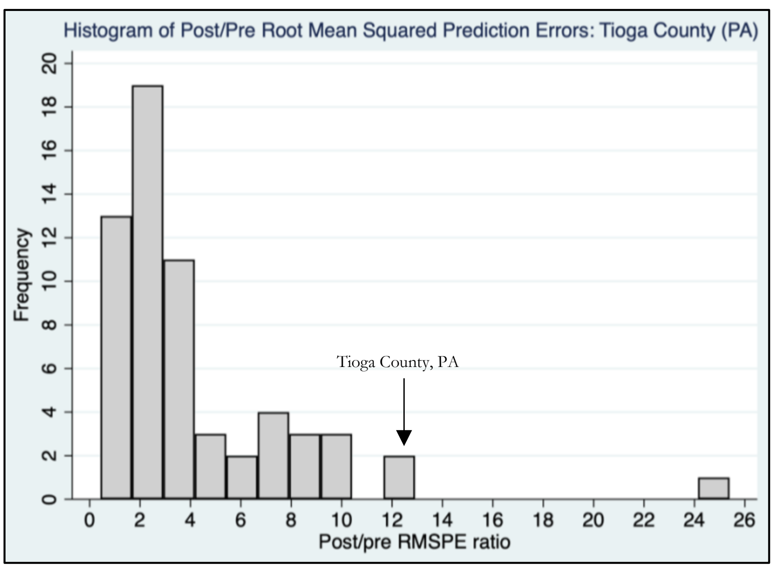
After calculating the post-period and pre-period Root Mean Squared Prediction Errors (RMSPEs), a "ratio of post- to pre-(fracking boom) RMSPE(s)" (Cunningham, 2021) is obtained. If a county has a high ratio compared to other counties in the "distribution of ratios" (Abadie et al., 2010, p.503), it is unlikely the result (the diverging population trends between the actual and synthetic counties between 2008 and 2020) is due to chance (Abadie et al., 2010; Cunningham, 2021). Graphs 8, 9, and 10 below highlight the ratios for each Pennsylvania county compared to the ratios of New York counties. Table 4 displays the rank and p-values for Bradford, Susquehanna, and Tioga Counties.



Graph 8: Histogram depicting post-to-pre-fracking boom Root Mean Squared Prediction Errors (RMSPE) for Bradford County, PA (Cunningham, 2021). X-axis corresponds to the ratio of post-fracking boom (i.e., 2008-2020) to pre-fracking boom (i.e., 2000-2007) RMSPE for each New York county, plus the treatment county of interest—Bradford County, PA. The Y-axis shows the number of counties achieving a specific post/pre RMSPE ratio. A high relative ratio (i.e., to the right of the distribution) signifies the difference between the synthetic and actual population trends is unlikely due to chance. See Table 4 and the accompanying footnote for additional details on the specific counties included in the histogram.



Graph 9: Histogram depicting post-to-pre-fracking boom Root Mean Squared Prediction Errors (RMSPE) for Susquehanna County, PA (Cunningham, 2021). X-axis corresponds to the ratio of post-fracking boom (i.e., 2008-2020) to pre-fracking boom (i.e., 2000-2007) RMSPE for each New York county, plus the treatment county of interest—Susquehanna County, PA. The Y-axis shows the number of counties achieving a specific post/pre RMSPE ratio. A high relative ratio (i.e., to the right of the distribution) signifies the difference between the synthetic and actual population trends is unlikely due to chance. See Table 4 and the accompanying footnote for additional details on the specific counties included in the histogram.



Graph 10: Histogram depicting post-to-pre-fracking boom Root Mean Squared Prediction Errors (RMSPE) for Tioga County, PA (Cunningham, 2021). X-axis corresponds to the ratio of post-fracking boom (i.e., 2008-2020) to pre-fracking boom (i.e., 2000-2007) RMSPE for each New York county, plus the treatment county of interest—Tioga County, PA. The Y-axis shows the number of counties achieving a specific post/pre RMSPE ratio. A high relative ratio (i.e., to the right of the distribution) signifies the difference between the synthetic and actual population trends is unlikely due to chance. See Table 4 and the accompanying footnote for additional details on the specific counties included in the histogram.

Table 4: Post-Pre-Fracking Boom RMSPE Ratio Ranks and P-Values: Bradford, Susquehanna, and Tioga Counties

County	Rank*	P-Value
Bradford County, PA	2nd of 61	0.033
Susquehanna County, PA	4th of 59	0.068
Tioga County, PA	3rd of 61	0.049

*There are 62 total potential donor counties in New York. However, each placebo run includes the county of interest, bringing the potential donor counties to 63 (62 counties in New York + 1 (Bradford, Susquehanna, and Tioga individually for each run; however Susquehanna and Tioga Counties were not included in the placebo run for Bradford County, Bradford and Tioga Counties were not included for the placebo run for Susquehanna County, and Bradford and Susquehanna Counties were not included for the placebo run for Tioga County)). STATA was not able to calculate a ratio for each donor county in New York. Hence, we excluded Hamilton County, NY and Schuyler County, NY in Bradford County, PA's placebo run (63-2=61 possible ratios); Broome County, NY, Hamilton County, NY, Onondaga County, NY, and Queens County, NY in Susquehanna County, PA's placebo run (63-4=59 possible ratios); and Chenango County, NY and Hamilton County, NY in Tioga County, PA's placebo run (63-2=61 possible ratios). Due to the large number of potential donor counties, and therefore the large denominator, these slight reductions do not substantially change the results.

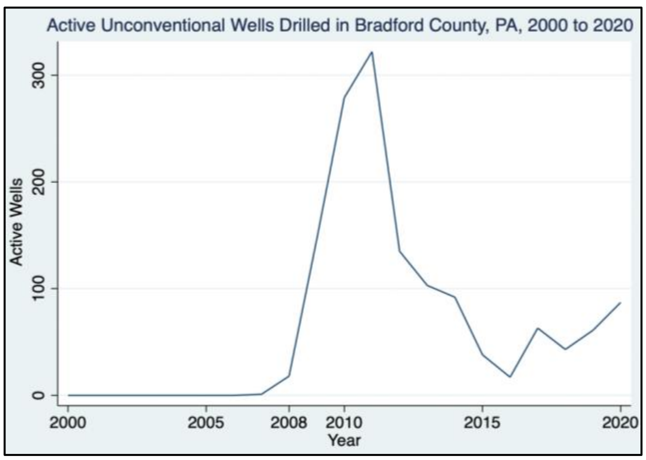
Hence, shown in Table 4, it can be concluded that, at the 95% confidence level, the fracking boom resulted in a statistically significant increase in population in Bradford and Tioga Counties, while, at the 90% confidence level, the fracking boom resulted in a statistically significant decrease in population in Susquehanna County (Abadie et al., 2010; Cunningham, 2021).

Indeed, as these data indicate, the impact of fracking on population is not homogenous between all three study counties. Specifically, in both Bradford and Tioga Counties, actual population counts shift dramatically upwards above their respective synthetic trends before declining again around 2012-2013. Moreover, unlike its neighboring counties, Susquehanna never experiences a substantial population increase above its synthetic trend in the post-fracking period, instead seeing a decline in population after 2008 which grows more pronounced after approximately 2012. In 2020, the last year of this analysis, Graphs 5 and 6 reveal that fracking increased population in Bradford and Tioga Counties by approximately 1,600 and 1,500 individuals, respectively, while Graph 7 reveals that fracking reduced population in Susquehanna County by nearly 2,000 individuals.

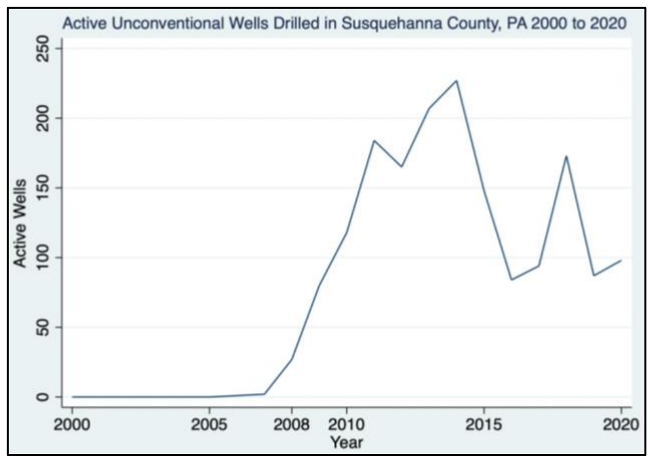
5. Discussion

5.1: Differential Effects: Bradford and Tioga vs. Susquehanna County

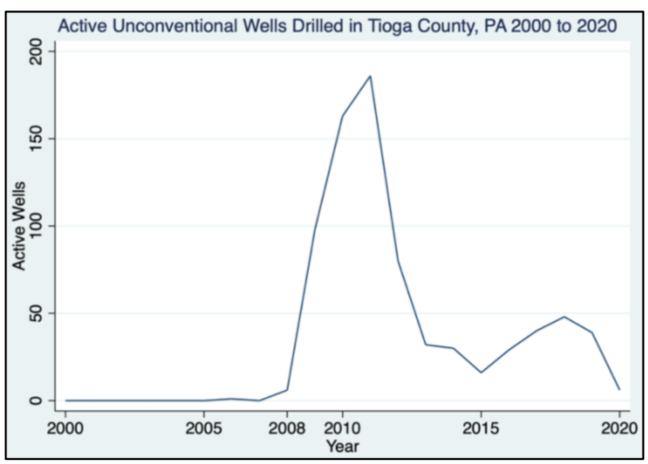
Experiencing a continued population decline after 2008, Susquehanna County differentiates itself from its neighboring counties. One potential factor explaining these differences is the variability in fracking activity (i.e., number of fracking wells) in Bradford and Tioga Counties versus Susquehanna County. To explore whether intercounty variation in fracking activity contributed to these differential effects, data from Pennsylvania's Department of Environmental Protection (DEP)—a state government agency which reports fracking-related information—are employed to plot the number of fracking wells (unconventional wells) drilled in each county throughout the research period, shown in Graphs 11, 12, and 13 below.



Graph 11: Bradford County Fracking Wells Drilled, 2000 to 2020; Graphs depict active unconventional wells drilled in the county within a given year; Source: Pennsylvania Department of Environmental Protection, n.d.*



Graph 12: Susquehanna County Fracking Wells Drilled, 2000 to 2020; Graphs depict active unconventional wells drilled in the county within a given year; Source: Pennsylvania Department of Environmental Protection, n.d.*



Graph 13: Tioga County Fracking Wells Drilled, 2000 to 2020; Graphs depict active unconventional wells drilled in the county within a given year; Source: Pennsylvania Department of Environmental Protection, n.d.*

*Pennsylvania Department of Environmental Protection. (n.d.). Retrieved from http://cedatareporting.pa.gov/Reportserver/Pages/ReportViewer.aspx?/Public/DEP/OG/SSRS/Wells_Drilled_By_County.

As Graphs 11, 12, and 13 highlight, fracking activity contrasts across borders, most notably between Bradford and Tioga Counties and Susquehanna County. In fact, from 2008 to 2020, there is a significant, positive correlation between population and fracking activity (as a function of the number of active wells) in Bradford and Tioga Counties, but not in Susquehanna County, shown in Table 6 below. Hence, in Susquehanna County, unlike in Bradford and Tioga Counties, population is not demonstrably tied to the number of fracking wells*.

Table 6: Correlation Between Population and Active Unconventional Wells, 2008 to 2020*

County	Correlation Coefficient
Bradford County, PA	0.6272**
	(0.0218)
Tioga County, PA	0.5135*
	(0.0727)
Susquehanna County, PA	0.0637
	(0.8361)

*p<.10 **p<.05 ***p<.001; parentheses indicate p-values.

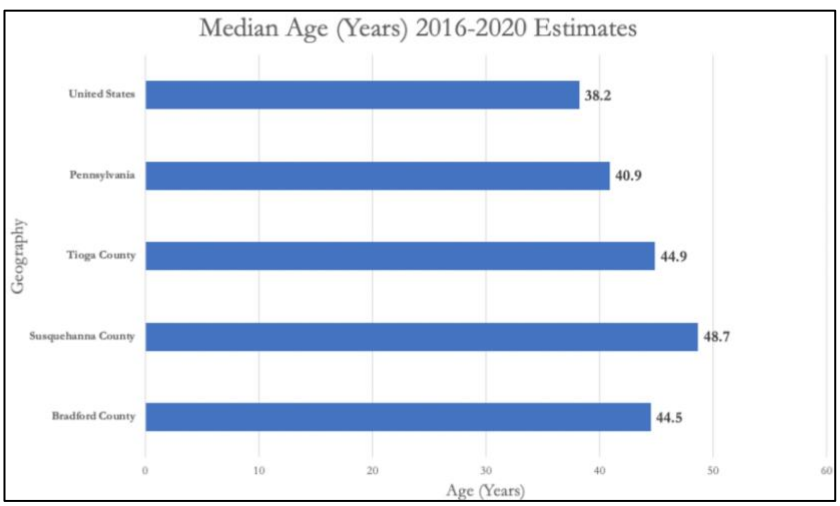
Another potential explanation for Susquehanna County's incongruous population trends is its proximity to larger population centers and interstate highway systems (Kelsey et al., 2012). Specifically, most of Susquehanna County is less than an hour's drive from two large metropolitan areas—Binghamton, New York and Scranton/Wilkes-Barre, Pennsylvania—which not only contain more amenities, but also likely have larger available stocks of housing for workers (Kelsey et al., 2012). Combined with easy access into Susquehanna County through Interstate 81 (I-81), which runs through Binghamton, Susquehanna County, and Scranton/Wilkes-Barre, workers have less incentive to migrate to Susquehanna County and instead commute from larger, more attractive population centers (Kelsey et al., 2012). Contrastingly, Bradford and Tioga Counties neither contain robust interstate roadways nor are proximate to large metropolitan areas. Hence, unlike in Susquehanna County, individuals employed in Bradford and Tioga's fracking industries are potentially more compelled to reside within their respective counties of work, accounting for the sharp increase in population following the fracking boom.

*Note: The fracking boom of 2008 does indeed significantly impact population in Susquehanna County, as demonstrated in the synthetic control analysis; however, *the number of fracking wells* is not significantly correlated with population in Susquehanna County, shown in Table 6
.

5.2: Declining Populations in All Counties

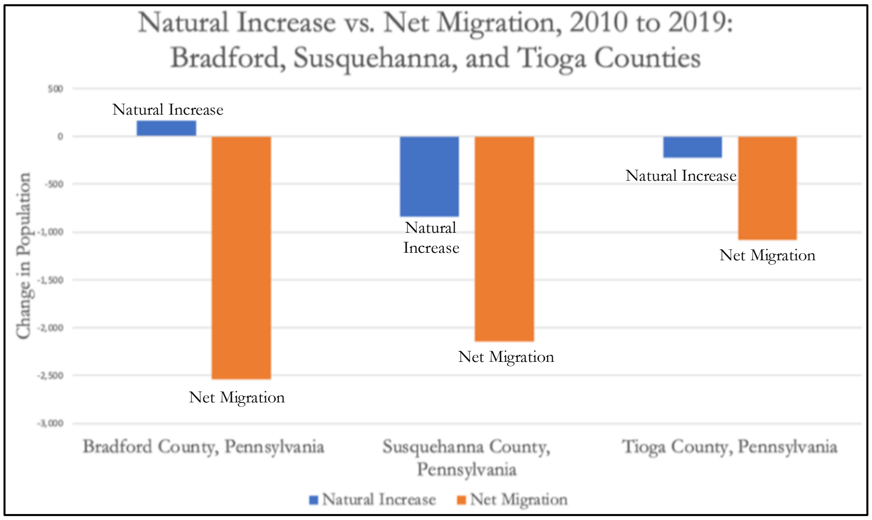
Although the synthetic control analysis suggests that Bradford and Tioga Counties experienced increases in population greater than what would have occurred if not for fracking, they eventually experienced precipitous declines in population—particularly after 2012-2013—to levels not seen in decades. Hence, despite fracking's promise to promote broad economic stimulus and create numerous jobs, the overall population losses in Bradford, Susquehanna, and Tioga Counties are emblematic of the natural gas industry's inability to retain or attract sufficient numbers of residents to offset losses.

While many reasons for these dramatic downturns in population exist, one potential explanation pertinent to each county is their aging populations, resulting in more deaths and fewer births (Cromartie, 2021). In other words, the natural increase (births minus deaths) in Bradford, Susquehanna, and Tioga Counties may be negative, driving down population (a 'natural decrease' in population) (U.S. Census Bureau Natural Increase, 2021). Graph 14 below demonstrates the older populations of these rural fracking counties—where, between 2016 and 2020, the median age of residents in Bradford, Susquehanna, and Tioga Counties is substantially greater than that of residents in Pennsylvania and the rest of the country (U.S. Census Bureau. (n.d.(a)).



Graph 14: Aging Populations between 2016 and 2020; Source: U.S. Census Bureau, 2016-2020 American Community Survey 5-Year Estimates, U.S. Census Bureau. (n.d.(a)).

However, seen in Graph 15 below, the evidence does not support the assertion that more deaths and fewer births are the main contributors to these population shifts. Specifically, although deaths surpassed births between 2010 and 2019 (with the exception of Bradford County), out-migration in each county outpaced in-migration by a substantial margin[2] and accounts for the largest share of population decline across all three regions. Hence, these data suggest that the drop in population stems from people moving out of Bradford, Susquehanna, and Tioga Counties rather than additional deaths.



Graph 15: Drivers of Population Change, 2010 to 2019.

"Source: Estimates of the Components of Resident Population Change for Counties in Pennsylvania: April 1, 2010 to July 1, 2019 (2021) (CO-EST2019-COMP-42); U.S. Census Bureau, Population Division (Release Date: March 2020)"

A potential fracking-related explanation for these population changes is the drop in natural gas prices. In 2008, the year of the fracking boom, the price of a million BTUs (British Thermal Units) of natural gas reached $8.86, a ten-year high, adding possible incentives for natural gas companies to increase their fracking activity and take advantage of prime market prices (EIA, 2022a). However, as nationwide natural gas output increased, its price eventually decreased, slowing exploration (highlighted in Graphs 11 and 13, where the number of fracking wells peaked before dropping precipitously around 2012 and 2013 in Bradford and Tioga Counties)[3] (EIA, 2022a; EIA, 2022b; Falchek, 2012).

With lower natural gas prices and less fracking activity, corporations likely experienced less demand for workers in fracking regions (Falchek, 2012). Hence, the decrease in fracking—a crucial economic booster to rural areas such as Bradford, Tioga, and Susquehanna—combined with lagging effects from the 2008 recession, protracted local economies, already limited job opportunities, and aging populations potentially helped accelerate rural brain drain and population decline around 2012-2013 in all three counties[*] (Falchek, 2012; Ventello, 2012).

2. Due to space constraints, and to maintain the paper's focus, the destination of migrants is not included. However, the vast majority of migration is occurring domestically, where individuals are leaving these counties for other areas within the United States. Data from the Census Bureau suggest many individuals are moving to other counties in Pennsylvania and New York. See the "Census Flows Mapper" at https://flowsmapper.geo.census.gov/map.html for additional information on where residents are moving. U.S. Census Bureau. (n.d.). Census Flows Mapper. U.S. county migration patterns. Retrieved June 28, 2022, from https://flowsmapper.geo.census.gov/map.html

3. There is more volatile fracking activity in Susquehanna County (Graph 12) than in Bradford and Tioga Counties (Graphs 11 and 13). According to experts and those familiar with fracking in the region, the reasons for this are not well known. However, anecdotally, anonymous, expert sources suggest that corporations possibly perceived Susquehanna County to be more productive in producing natural gas; hence, companies initially continued to explore in the county despite the drop in natural gas prices. This suggestion of productivity is substantiated by Pennsylvania Department of Environmental Protection (DEP) data, where "the top 13 wells in (Pennsylvania in the last half of 2013 were in)... Susquehanna County" (Gibbons, 2014). Eventually, seen in Graph 12, fracking activity did indeed decelerate in Susquehanna County.

*Estimates of the Components of Resident Population Change for Counties in Pennsylvania: April 1, 2010 to July 1, 2019. (2021). Estimates of the Components of Resident Population Change for Counties in Pennsylvania: April 1, 2010 to July 1, 2019 . Retrieved June 28, 2022, from https://www.census.gov/data/tables/time-series/demo/popest/2010s-counties-total.html.

Additionally, large population leaps seen in Bradford and Tioga Counties around the onset of the fracking boom likely do not return during the study period since, even with the occasional bumps in natural gas prices between 2013 and 2020, corporations likely have fewer positions to fill at fracking sites relative to the early years of fracking (i.e., 2008) as innovation and automation increase (EIA, 2022a). This may be especially true for fracking roles that were deemed potentially dangerous or hazardous to humans[4]. Fewer job openings would lead to companies hiring fewer workers in fracking regions.

5.3a: Effects of Fracking-Induced Population Changes: Congressional Representation and Political Clout

One of the most critical implications of these dynamic population shifts in Bradford, Susquehanna, and Tioga Counties is political representation. Specifically, "the Constitution provides that each state will have a minimum of one member in the U.S. House of Representatives, and then the apportionment ('the process of dividing the 435 memberships, or seats, in the House of Representatives...') calculation divides the remaining 385 seats among the 50 states" (U.S. Census Bureau, 2021(a)(c)(d)). Hence, since the number of representatives in Congress is fixed at 435, the number of seats a state is allocated, and how those seats are allocated within a state, are directly tied to an area's population (U.S. Census Bureau, 2021(a)(c)(d)).

Following the completion of the Census, each state is allocated a specific number of districts based on an apportionment formula selected by Congress (U.S. Census Bureau, 2021(a)(c)(d)). Each district within a given state is divided almost equally among the state's population, where, "based on the 2020 Census, the average number of people per representative in the U.S. House of Representatives is 761,169" (U.S. Census Bureau, 2021(d)). Hence, rural Congressional districts tend to be geographically larger than urban districts, as rural population densities are comparatively lower and therefore require larger geographic boundaries to bring together over 760,000 individuals within their borders (U.S. Census Bureau, 2021(d)). Figure 3 demonstrates the size of each district in Pennsylvania using the new 2022 maps (based on the 2020 Census), where rural districts in the state (e.g., 15th Congressional district) are geographically larger than urban districts in the state (e.g., 3rd Congressional district encompassing the city of Philadelphia).

4. The authors would like to thank an anonymous expert from the Pennsylvania State University for highlighting these potential factors.

*Note: While the number of fracking wells drilled is not directly correlated with population in Susquehanna County, the decrease in natural gas prices and, subsequently, broad fracking activity may have interacted with Susquehanna's already deteriorating economic conditions to help foster further economic and population declines (evidenced by the significant population declines following the 2008 fracking boom demonstrated in my synthetic control analysis).

If rural counties such as Bradford, Susquehanna, and Tioga lose population, their broader Congressional districts may not only geographically enlarge, but population shifts may also alter these counties' Congressional representatives—a phenomenon transpiring in the 2022 redrawing of districts based on the 2020 Census. Specifically, due to Pennsylvania's shifting population dynamics, Bradford, Susquehanna, and Tioga Counties are each represented by a different member of Congress. While each county continues to be represented by members of the Republican party, because these Congressmen previously represented other districts with varying economies, industries, and geographies, they are likely less familiar with the issues facing Bradford, Susquehanna, and Tioga counties—which may differ from the issues present in their previous districts.

Beyond changes to Congressional representatives, larger districts also mean representation is spread thin across vast geographic landscapes, making it difficult for communities to make their voices heard (Hughes, 2021; Kopko, 2021). Specifically, rural residents are faced with limited internet access and—without the option to electronically connect—constituents must occasionally travel hours to contact their member of Congress (Hughes, 2021; Kopko, 2021). Moreover, due to the expansive geography of rural districts, the per capita cost of delivering government services will subsequently increase (Hughes, 2021; Kopko, 2021). In essence, larger Congressional districts—particularly those encompassing rural areas such as Bradford, Susquehanna, and Tioga Counties—may lead to a reduction in political clout for individual communities while forcing them to compete for community-specific government resources (e.g., school district funding, health care investment, local economic stimulus) with other areas that may be within the same district, but are geographically distant and experience varying needs (Hughes, 2021; Kopko, 2021). Ultimately, the fracking boom's failure to promote sustained population growth, despite promises of enhanced economic opportunities, is one (but certainly not the only) factor contributing to the necessity for larger districts and, subsequently, more diluted political representation[5].

5. Population also impacts the drawing of districts for the Pennsylvania Legislature (House of Representatives and Senate), with 203 districts in the state House of Representatives composed of about 64,000 individuals each, and 50 districts in the state Senate composed of approximately 260,000 individuals each (Hughes, 2021). However, the scope of this paper is limited to federal House districts due to space constraints and to avoid complicating the analysis for audiences who may be unfamiliar with state-specific political systems.

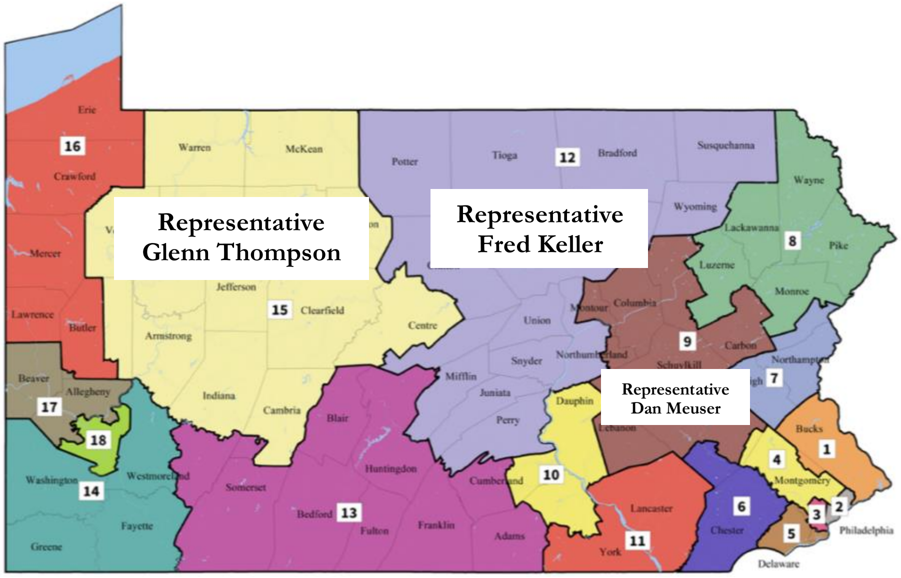


Figure 2: 2018 Congressional districts before 2020 Census. Numbers represent Congressional district. Photo Source: Pennsylvania Department of State (2018). https://www.dos.pa.gov/VotingElections/CandidatesCommittees/RunningforOffice/Pages/2018-Remedial-Congressional-Districts.aspx **Color Required**

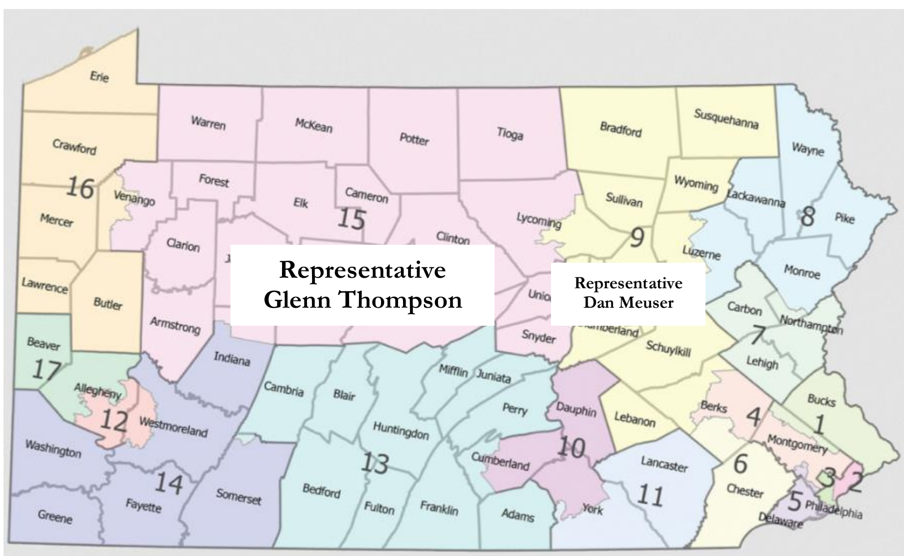


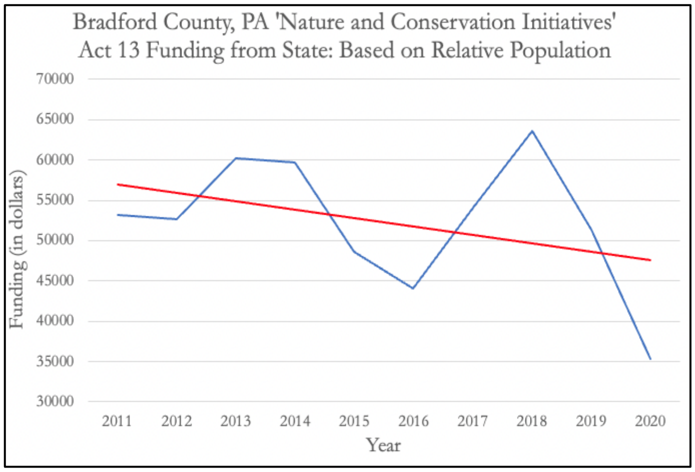
Figure 3: 2022 Congressional districts based on 2020 Census. Numbers represent Congressional district. Released by Pennsylvania Supreme Court. Photo Source: . Supreme Court of Pennsylvania. (2022). https://www.pacourts.us/2022-redistricting-opinions; https://www.vote.pa.gov/Pages/Pennsylvania-Redistricting-US-Congress.aspx **Color Required**

5.3b: Effects of Fracking-Induced Population Changes: Act 13: Marcellus Legacy Fund

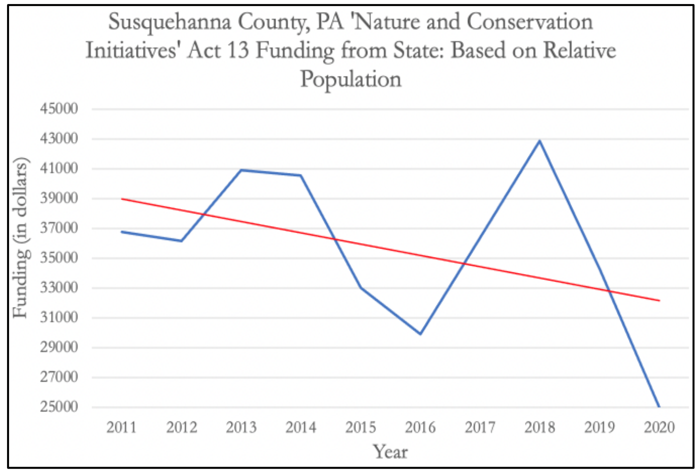
In 2012, the Pennsylvania state government enacted legislation intended to collect revenue from the abundant fracking activity within its borders (Pachon & Weber, 2015; PA Public Utility Commission Act 13 Impact Fee, n.d.). Although criticized for its insufficiencies in capturing the full breadth of potential revenue from the natural gas industry, the culmination of this effort came in the form of "Act 13," which "provides for the imposition of an unconventional gas well fee (also called an impact fee), and the distribution of those funds to local and state governments" (PA Public Utility Commission, n.d.; StateImpact Pennsylvania, n.d.). Broadly, funds from the impact fee are funneled into a variety of programs, including the "construction, reconstruction, maintenance and repair of roadways, bridges and public infrastructure," "projects to increase the availability of safe and affordable housing to residents," and "judicial services" (PA Public Utility Commission, n.d.; Pennsylvania Legislature, 2012).

Population is a central component of the state's calculated distribution of funding from Act 13 through its establishment of the "Marcellus Legacy Fund," which similarly "provide(s) for the distribution of unconventional gas well impact fees to counties, municipalities and commonwealth agencies" (State of Pennsylvania, n.d.; PA Public Utility Commission, n.d.). Specifically, forty percent of the Legacy Fund's disbursement is contingent upon a county's population relative to the state's total population (Pennsylvania Legislature, 2012; Pennsylvania Department of Transportation, n.d.).

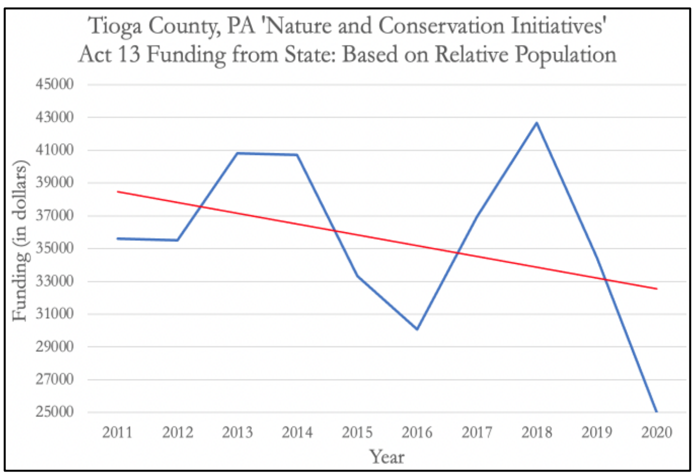
Because portions of the Act 13 funding formula distribute money to counties based on their populations *relative* to the total population of the state, Bradford, Susquehanna, and Tioga Counties—which all experienced eventual declines in population following the fracking boom—are, in essence, competing for portions of Legacy Fund monies with urban counties that experience faster population growth and are not directly affected by fracking's adverse health and environmental impacts (Pennsylvania Legislature, 2012; Pennsylvania Department of Transportation, n.d.). Hence, post-boom (2008 to 2020), fracking counties experience a 'triple blow' to their environmental and socio-political standing: (1) they must bear the brunt of any health and environmental implications related to fracking; (2) declining populations contribute to, among other factors, less political clout and more diluted political representation (highlighted above); and (3) less population means relatively less money from the Legacy Fund to help counteract the adverse effects of fracking (Section 2315(a.1)(5) of Pennsylvania Act 13 of 2012, 2012).



Graph 16: Bradford County Funding Based on Population—Section 2315(a.1)(5) of Act 13 of 2012; red line is the 'trend line' demonstrating the decrease in funding over time. Data source: PA Public Utility Commission County Impact Fee Distribution, n.d. **Color Required**



Graph 17: Susquehanna County Funding Based on Population—Section 2315(a.1)(5) of Act 13 of 2012; red line is the 'trend line' demonstrating the decrease in funding over time. Data source: PA Public Utility Commission County Impact Fee Distribution, n.d. **Color Required**



Graph 18: Tioga County Funding Based on Population—Section 2315(a.1)(5) of Act 13 of 2012; red line is the 'trend line' demonstrating the decrease in funding over time. Data source: PA Public Utility Commission County Impact Fee Distribution, n.d. **Color Required**

Despite receiving less funding under certain provisions of the Legacy Fund, fracking counties are generally, but not always, allocated more money than non-fracking counties; the broad impact fee formula integrates into its calculations the number of fracking wells contained within a jurisdiction (Section 2314(d)(1) Pennsylvania Act 13 of 2012, 2012; PA Public Utility Commission, n.d.). However, as demonstrated in Graphs 16, 17, and 18—even within the constraints of legislation (Act 13) meant to "benefit municipalities that may be impacted by the development of unconventional gas resources" (Marie, 2019; Snyder Brothers v. Pennsylvania Public Utility Commission, 2018)—

Note: The increase in funding in 2018 was due to a Pennsylvania Supreme Court ruling in *Snyder Brothers v. Pennsylvania Public Utility Commission* related to "'Stripper well(s)' (or a fracking well) incapable of producing more than 90,000 cubic feet of gas per day during any calendar month" (Section 2301 of Pennsylvania Act 13 of 2012, 2012), which were previously exempt from the impact fee (Section 2301 of Pennsylvania Act 13 of 2012, 2012; Cusick, 2019; Marie, 2019; Snyder Brothers v. Pennsylvania Public Utility Commission, 2018). However, the court's decision increased the number of wells eligible for the impact fee charge, consequently resulting in increased revenue disbursed to local counties (Cusick, 2019; Marie, 2019; Section 2301 of Pennsylvania Act 13 of 2012, 2012; Snyder Brothers v. Pennsylvania Public Utility Commission, 2018).

declining populations can result in tens of thousands of fewer dollars going to rural regions in urgent need of additional government funds, even with fracking resulting in slightly higher total populations in Bradford and Tioga Counties than what was to be expected had the fracking boom not materialized. Yet, Susquehanna experienced considerable declines in population due to fracking, lacking the post-boom population spikes seen in Bradford and Tioga Counties. Hence, fracking may have helped partially buffer the loss in portions of the Legacy Fund monies allocated to Bradford and Tioga Counties while simultaneously amplifying Susquehanna's loss in revenue. Nevertheless, Susquehanna County makes up for this loss through other portions of Act 13 funding—receiving some of the most money in the state from impact fees due to the prolific fracking activity within its jurisdiction (PA Public Utility Commission, n.d.).

6. Conclusion

Depopulation and economic uncertainty threaten the vitality of rural communities across the United States and the world. Deficiency of well-paying jobs, exodus of working-age youth, shrinking tax bases, and underinvestment in infrastructure and attractive amenities work in tandem to generate a perpetual cycle of rural decay (Carr & Kefalas, 2010; Davis et al., 2022; Dobis et al., 2021; Johnson & Lichter, 2019). However, for rural communities blessed with shale gas, the fracking boom promised to be a turning point in their plight. Hence, the central goal of this analysis was to understand the true demographic and socio-political impacts of fracking by examining its effects on population and socio-political changes in three of the most prominent rural fracking counties in Pennsylvania—Bradford, Susquehanna, and Tioga.

The three synthetic control models and statistical inference using placebo tests demonstrate significant effects of fracking on population across Bradford, Susquehanna, and Tioga Counties. While all three counties eventually saw population declines relative to their pre-period levels, fracking significantly, though only slightly, increased populations in Bradford and Tioga Counties to levels greater than they would have been had fracking not materialized. However, fracking exacerbated population decline in Susquehanna County.

The small population increases in Bradford and Tioga Counties, population decrease in Susquehanna County, and the eventual population decline across all three regions demonstrate that, despite its promises to bring economic renewal to struggling communities, the natural gas industry failed to substantially improve the demographic situations plaguing these rural counties, specifically population decline. Consequently, Bradford and Susquehanna Counties and Tioga County will not only be split up in their new Congressional districts, but both groups of counties will also likely be represented by a new member of Congress—one who may not directly understand the unique needs of these regions. Moreover, Bradford, Susquehanna, and Tioga Counties are covered in geographically large districts that span sizable swaths of the state, making it challenging for individual counties and municipalities to be "seen" and forcing them to compete for government services with other localities across the district that may be geographically distant and experience wholly different needs—in essence diluting political representation (Hughes, 2021; Kopko, 2021; U.S. Census Bureau, 2021(d)).

This analysis further reveals that despite their significant role in contributing to natural gas production in the state, due to their declining populations, Bradford, Susquehanna, and Tioga Counties receive less funding over time from Pennsylvania's disbursement of Act 13 Marcellus Legacy funds for projects such as the "rehabilitation and repair of greenways, recreational trails, open space, (and) natural areas..." (Section 2315(a.1)(5) of Pennsylvania Act 13 of 2012, 2012). Although the prolific fracking activity in Bradford, Susquehanna, and Tioga allows the counties to make up for this loss in Marcellus Legacy funding, it is nevertheless pernicious, and ironic, that some of the most affected counties by natural gas drilling benefit relatively little from this provision of a law with an overarching purpose to "benefit municipalities that may be impacted by the development of unconventional gas resources" (Marie, 2019; Snyder Brothers v. Pennsylvania Public Utility Commission, 2018). Leaders from other states and countries where fracking is prevalent can learn from Pennsylvania's Act 13 shortcomings by ensuring the distribution of extraction-related tariffs is equitably distributed to front-line communities most acutely affected by drilling's presence.

There are many additional opportunities for scholars interested in continuing the research presented here to both bolster the current literature and address this paper's key limitations. Firstly, this research employs population estimates derived from the U.S. Census Bureau. Although reputable, population estimates may nevertheless yield less accurate results compared to actual population counts (U.S. Census Bureau, 2021b, p.1). Hence, prospective researchers may strive to incorporate only true population figures in future analyses examining the demographic consequences of fracking. Secondly, this analysis does not include in its results the substantial number of transitory workers moving into and out of fracking regions. Since this paper focuses on more permanent populations, counting the transitory workforce is beyond the scope of this research. Nevertheless, transitory workers remain an integral part of the fracking process and estimating their impact on local populations may be of interest to scholars looking to study temporary population shifts in drilling areas. Thirdly, this paper focuses on the county level of analysis. However, there may also be intermunicipal variations in drilling activity and subsequent population responses. If reliable data are available, future research should examine the demographic and socio-political effects of fracking on an even more micro level to garner a greater understanding of the local implications of the practice. Lastly, this paper focuses on three of Pennsylvania's most prominent fracking counties. Future research can expand the scope of this analysis by examining the demographic and socio-political impacts of fracking in other parts of the state or regions of the country where the practice is similarly flourishing, such as Texas, Wyoming, and North Dakota. Exploring fracking's impacts in a variety of settings would help expand the breadth of current research while enabling scholars to understand the implications of the practice across politically, socially, and economically diverse populations.

Overall, the findings of this analysis contribute to the growing literature on fracking as natural gas continues to evolve into an integral part of global energy portfolios—from the United States to the United Kingdom. Practically, this research also informs the consequential debate around fracking's future in often-forgotten rural regions, adding to the discussion whether the practice's touted benefits outweigh its various consequences. Ultimately, while drilling proponents continue to highlight fracking's role in empowering struggling regions, lingering demographic and socio-political issues suggest some rural communities failed to receive the full memo.

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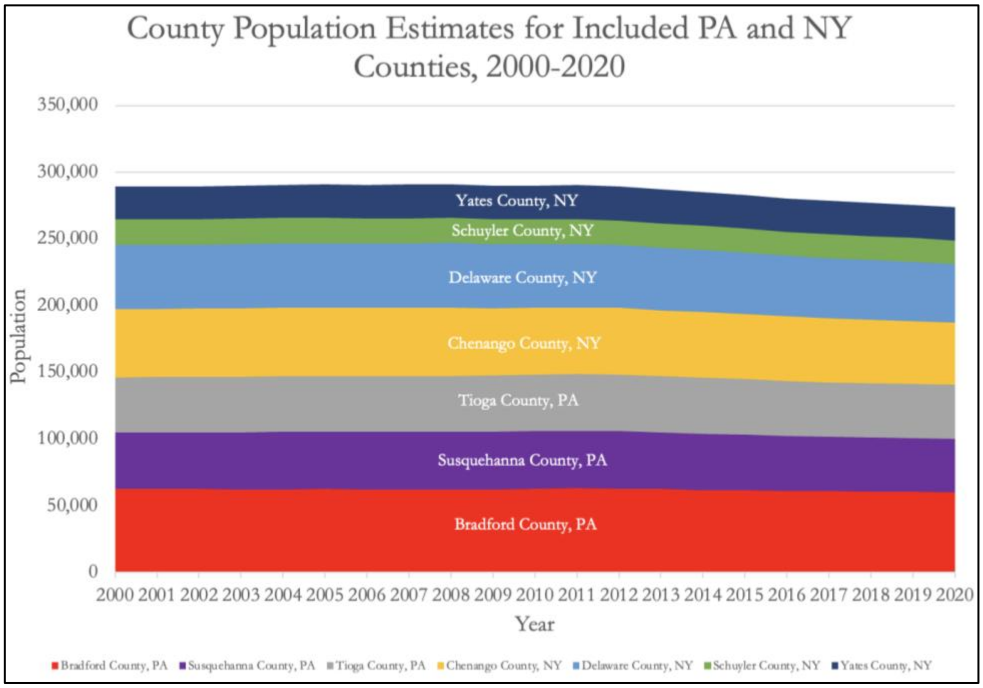
Appendix



Graph 1: County population estimates for included PA and NY counties, 2000-2020; Note the similar population trends between counties. Data source: U.S. Census Bureau "County Intercensal" (2000-2010) and "Vintage 2020" (2010-2020) datasets. **Color Required**.

Table 5: Bradford, Susquehanna, and Tioga Counties Predictor Values: Actual vs. Synthetic

Predictor/County	Actual Bradford County, PA	Synthetic Bradford County, PA	Actual Susquehanna County, PA	Synthetic Susquehanna County, PA	Actual Tioga County, PA	Synthetic Tioga County, PA
Personal Income (in thousands of dollars)	1585001	1634552	1132112	1154809	979794.4	999479.3
Per-capita Personal Income (in dollars)	25367.88	26404.76	26414.38	26387.84	23601.13	24142.45
Total Population: Female	31927.13	31824.66	21457.88	21401.61	21166.5	20896.94
Total Population: Male	30562.88	30629.95	21376.25	21372.14	20351	20602.88
Population: White Male	29945.13	29790.08	21072.75	20586.56	19954.38	20042.33
Population: White Female	31303.5	31021.86	21186.13	20965.68	20753.63	20416.38
Population: Black or African American Male	179.375	336.8832	90.5	489.228	153	222.3899
Population: Black or African American Female	118.75	252.7936	62.5	124.9245	129.875	140.7153
Population: American Indian and Alaska Native Male	82.625	87.16575	33.625	55.70612	44.375	65.79563
Population: American Indian and Alaska Native Female	99.5	78.24938	30.75	43.14037	50.625	61.03288
Population: Asian Male	145.75	150.612	45.25	74.46438	58.875	93.30575
Population: Asian Female	172.875	195.1848	58.75	104.2634	84.625	109.0218
Population: Native Hawaiian and Other Pacific Islander Male	2.5	7.62925	4.125	7.916125	2.375	3.211375
Population: Native Hawaiian and Other Pacific Islander Female	3.25	5.92425	5.375	5.538125	2.625	3.57625
Population: Two or More Races Male	207.5	257.5783	130	158.259	138	175.8489
Population: Two or More Races Female	229.25	270.6496	114.375	158.0658	145.125	166.2215
Total Population Among Ages 15 to 19 Years	4393.125	4714.579	3110.375	3176.67	3445.25	3676.127
Total Population: Male Among Ages 15 to 19 Years	2265.75	2435.142	1643	1674.014	1682.375	1908.801
Total Population: Female Among Ages 15 to 19 Years	2127.375	2279.437	1467.375	1502.656	1762.875	1767.326
Population: White Male Among Ages 15 to 19 Years	2210	2339.642	1608.25	1594.558	1623	1817.778
Population: White Female Among Ages 15 to 19 Years	2067	2191.457	1447.875	1458.856	1699.375	1693.399
Population: Black or African American Male Among Ages 15 to 19 Years	20.375	43.30938	9.375	51.07475	35	47.879

Population: Black or African American Female Among Ages 15 to 19 Years	12.5	34.37788	6	12.5195	30.125	29.94687
Population: American Indian and Alaska Native Male Among Ages 15 to 19 Years	5.375	7.787125	1.625	5.33825	5.25	6.571625
Population: American Indian and Alaska Native Female Among Ages 15 to 19 Years	10.375	6.26075	.875	3.522125	5.875	5.636625
Population: Asian Male Among Ages 15 to 19 Years	13.875	15.2745	5.5	7.936375	3.375	15.52988
Population: Asian Female Among Ages 15 to 19 Years	14.75	19.90413	3.125	10.23163	7.75	14.13162
Population: Native Hawaiian and Other Pacific Islander Male Among Ages 15 to 19 Years	0	.4315	1	.335625	0	.134875
Population: Native Hawaiian and Other Pacific Islander Female Among Ages 15 to 19 Years	0	.175375	.875	.78525	0	.346375
Population: Two or More Races Male Among Ages 15 to 19 Years	16.125	28.69738	17.25	14.77038	15.75	20.90713
Population: Two or More Races Female Among Ages 15 to 19 Years	22.75	27.26162	8.625	16.742	19.75	23.86525
Unemployment Rate (Annual Average)	4.875	4.877638	5.25	5.244988	5.8	5.148925

(Predictor wording from U.S. Census Bureau Intercensal Dataset, 2021; U.S. Census Bureau Vintage 2020 Dataset, 2022; BEA, n.d.; BLS, n.d.)

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