# What Drives the Fracking Boom Crime Relationship?
# A Fixed-Effects Analysis of Crime during the Pennsylvania Fracking Boom

A Thesis Presented
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ABSTRACT

WHAT DRIVES THE FRACKING BOOM CRIME RELATIONSHIP?
A FIXED-EFFECTS ANALYSIS OF CRIME DURING THE PENNSYLVANIA FRACKING BOOM

FEBRUARY 2022

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The rapid expansion of hydraulic fracturing(fracking) over the past two decades has led to an increasing interest in the relationship between natural resource booms and crime. Since the onset of the fracking boom, numerous anecdotal accounts and an increasing body of empirical studies have suggested that fracking has a significant, positive impact on crime. However, the mechanisms behind this relationship are poorly understood. This study uses a high-resolution dataset and a unique, fixed-effects approach to decompose the effect that fracking has on crime into increases due to the introduction of new wells and increases due to the presence of existing wells. The findings suggest that new wells have a different impact on crime than existing wells. Specifically, new wells result in greater increases in violent crimes. These results may indicate that the relationship between fracking and crime is largely driven by the influx of non-local, transient, fracking labor.

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# CHAPTER I

# INTRODUCTION

Natural gas is currently the most widely used fuel type for power generation in the United States, accounting for approximately 40% of electrical generation in 2020 (US EIA, 2021b). Of total natural gas production, tight gas and shale gas extracted by hydraulic fracturing (fracking) accounted for over 86% in 2020, which represents more than a 270% increase in fracking since 2000 as shown in Figure 1.

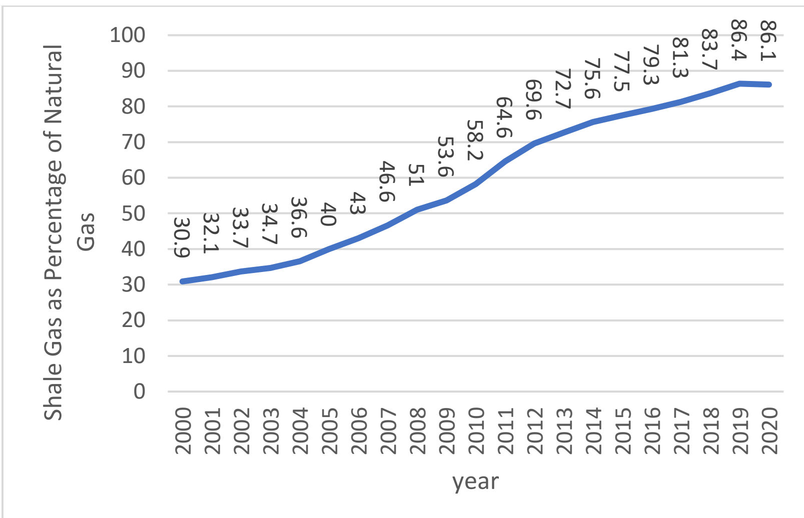


*Figure 1 Fracking Gas Production as Percentage of Total US Natural Gas Production* ***Source****: US EIA, 2021a.*

While there were 35 natural gas producing states in 2020, nearly 44% of all US production occurred in only two states, Texas (23.9%) and Pennsylvania (20%) (US EIA, 2021a). Pennsylvania's prominence as a natural gas producer is due to the fact that nearly 75% of Pennsylvania's land area lies over the Marcellus Shale Formation, a 95,000 square mile geological formation of organic-rich shale, which lies between 100 to 8,000 feet below sea level under five states: New York, Pennsylvania, Ohio, West Virginia, and Kentucky (US EIA, 2017). Of US shale formations, the Marcellus has by far the largest estimated volume of natural gas at

410.3 trillion cubic feet (US EIA, 2011), though only 214 trillion cubic feet is considered recoverable with current technology (US Geological Survey, 2019).

Pennsylvania has become the most productive Marcellus natural gas producer for at least four reasons: First, nearly 34,000 square miles of the Marcellus lie below Pennsylvania, which is over 35% percent of the Marcellus's total area and a larger area than lies under any other Marcellus state (US EIA, 2011). Second, the highest concentrations of natural gas in the Marcellus shale are believed to be located under north-central Pennsylvania and south-central New York (Lee et al., 2011). Third, in terms of natural gas extraction, the Marcellus is most productive at depths between 5,000-8,500 feet (Pennsylvania DEP, 2013), and the average depth of the Pennsylvanian Marcellus is approximately 6,600 (Lee et al., 2011). Finally, Pennsylvania has the longest history of fossil fuel production of all US states, being the birthplace of the US oil industry in 1859 (American Oil & Gas Historical Society, 2021; Madrigal, 2013; Susko, 2017), and as such, it has developed a civic, political, and regulatory culture amenable to natural resource extraction in contrast to a state such as New York, which has banned fracking (Nicks, 2014; Teirstein, 2021). These circumstances have contributed to the flourishing of unconventional (fracking) natural gas production in Pennsylvania, which has grown enormously over the past 20 years as shown in Figure 2.

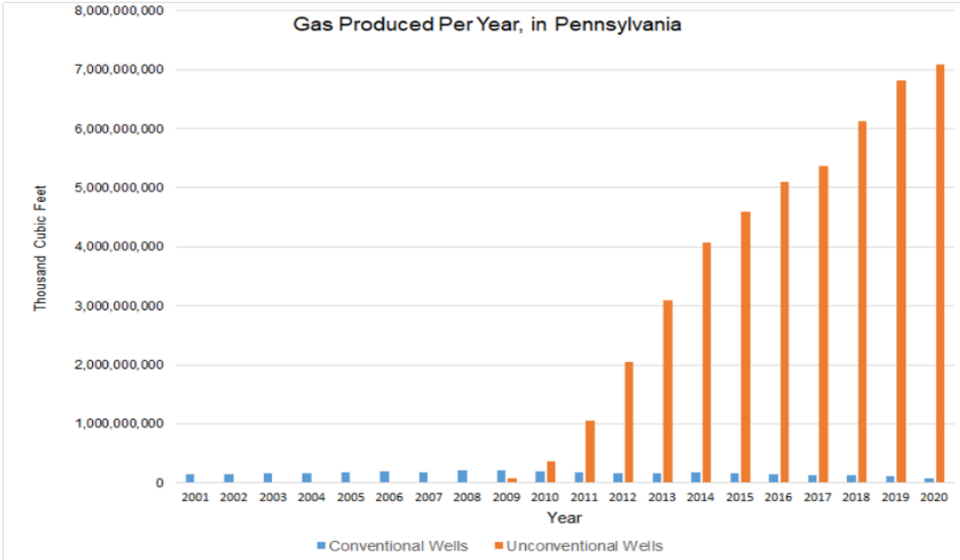


*Figure 2: Natural Gas Produced per Year in Pennsylvania. Source: Pennsylvania DEP 2021*

The trends shown in Figures 1 and 2 illustrate the dramatic increase in US natural gas production and particularly shale gas production that has occurred since the turn of the century. This development has been widely recognized as a natural resource boom (Archbold et al., 2014l; Gourley and Madonia, 2018; Lim, 2018; Mason, 2015; Wang and Krupnick, 2013), which is attributed to a variety of factors including high natural gas prices in the early 2000's, favorable government policies including tax and price incentives, and technological innovation that allowed for previously irrecoverable natural gas to be extracted (Wang and Krupnick, 2013).

The fracking boom has been a contentious issue since its inception. Public perception of fracking is sharply divided (Swift, 2015), and expert scientific and policy opinion is similarly split. Advocates of US fracking and natural gas have lauded it as a medium for improving US energy independence and national security (Matz and Renfrew, 2015; Sica and Huber, 2017), a lower GhG emission transition fuel that can serve to fill the gap between carbon-dense fossil fuels and sustainable energy sources (Stephenson et al., 2012; Wu et al. 2016), a means of protecting consumers from rising energy costs (Ochieng et al., 2015), and as a vehicle for local economic development (Cronshaw et al, 2016). However, critics of fracking have questioned the job-growth potential and magnitude of actual job growth attributable to fracking (Jerolmack, 2021), have argued that increased natural gas consumption will delay transition to green energy (Shearer etl al., 2014), and highlighted the various health and environmental externalities associated with fracking (Alexander et al., 2013; Black et al., 2021; Mehany et al., 2015).

However, it is undeniable that fracking impacts the communities in which it occurs. Popular reporting often highlights the negative social impacts that people perceive fracking to have on their communities, and these impacts are often attributed to the influx of fracking labor. For example, in 2014 *The Washington Post* reported that the North Dakota Bakken oil boom caused an influx of "oil workers living in sprawling 'man camps'" resulting in "a crime wave -- including murders, aggravated assaults, rapes, human trafficking and robberies -- fueled by a huge market for illegal drugs, primarily heroin and methamphetamine" (Horwitz, 2014). Long-term residents of communities in which fracking is introduced, often report that their communities are rapidly transformed into chaotic boomtowns in which quality of life is compromised by anti-social behavior (Ruddell and Ortiz, 2015). Indeed, popular accounts of the fracking boomtowns often describe them as a chaotic 'new wild west' in which crime runs rampant (Briody, 2015; CNBC, 2013; McDonnel & West 2012).

The self-reported and popular accounts of the community transformation and negative social impacts of the fracking boom are consistent with long-standing social theories of the origins of crime. The theory of social disorganization first expressed by sociologists Clifford Shaw and Henry D. McKay as an explanation for urban juvenile delinquency in 1969 (Bellair, 2017), and extended to explain the relationship between resource booms and crime by sociologists William Freudenburg and E.V. Kohr in the 1970s, contends that rapid population growth can impair communities' informal controls over behavior leading to an increase in anti-social behavior including crime (Ruddell, 2017). Additionally, there are several contending economic theories proffered to explain the relationship between natural resource booms and crime. However, the unique logistics of fracking make it unclear to what extent these existing theories apply to the fracking boom.

The fracking boom has given rise to renewed social science interest in boomtown effects. However, while a growing literature has empirically established a positive relationship between fracking and crime, no paper to my knowledge has been able to sufficiently decompose the effects of the fracking boom to establish evidence for the causal mechanism of the effect. By exploiting the geology of Pennsylvania, the exceptional intensity of fracking in Pennsylvania, the unique logistics of fracking, a high-resolution dataset, and employing a fixed-effects methodology for causal inference, this paper seeks to extend the existing literature on the relationship between fracking and crime by providing insight into mechanism between the fracking-crime relationship.

# CHAPTER II

# BACKGROUND

## A. The Marcellus Shale in Pennsylvania, and Shale Gas

Nearly 75% of Pennsylvania's land area and 45 of its 67 counties lie over the Marcellus Shale Formation as shown in Figure 3. The Marcellus Shale is a 95,000 square mile deposit of organic-rich black shale composed primarily of clay, quartz, feldspar, pyrite, calcite, and dolomite formed in the Appalachian Basin during the Devonian epoch approximately 390 million years ago (US EIA, 2017). Black shales such as the Marcellus are formed via the slow deposition and compression of silts, mud, and organic matter under calm, low-oxygen water, in the case of the Marcellus, under an ancient sea (Speight, 2016; Penn State Public Broadcasting, 2014). The relatively oxygen-free environment at the bottoms of ancient water formations prevented organic matter, mostly dead aquatic plants, from decomposing normally (Speight, 2016). Instead, organic matter became trapped under layers of silt and mud where, under immense pressure, it slowly broke down producing hydrocarbons, primarily methane, propane, butane, pentane, hexane, and heptane, which collectively are known as natural gas (Speight, 2016). As the shale formation continued to form, the natural gas became trapped in very thin layers and pores distributed throughout the formation (Penn State Public Broadcasting, 2014).

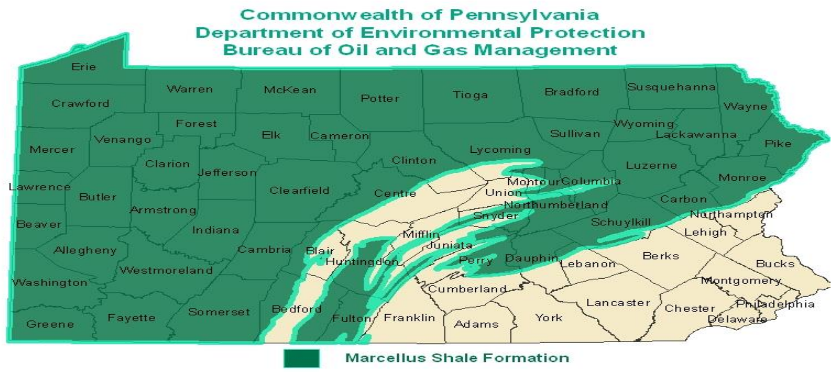


*Figure 3: Map of Pennsylvania with Counties and Marcellus Shale Formation: Source: Pennsylvania DEP*

## B. Hydraulic Fracturing, Unconventional Wells, and the Shale Gas Boom

The first commercial attempt to extract natural gas from shale occurred in New York in 1821 (US EPA, 2011). However, the distribution of natural gas in small amounts distributed throughout the shale formation, rather than in concentrated pools or veins as in the case of oil or coal, renders the extraction of the natural gas in shale technically and economically infeasible via conventional vertical wells. As such, though Pennsylvania has been known to be fossil fuel rich since the early nineteenth century, and though the Marcellus shale was fully surveyed and known to contain large amounts of natural gas since the 1970s, it was not until a combination of technological innovations came to fruition in the 1980s and 1990s, and not until favorable economic conditions developed in the early 2000s that natural gas extraction from shale became economically viable.

Fracturing is a long-used method in oil production that involves creating cracks (fractures) in rock formations to allow small deposits of natural resources to pool into a larger reservoir and be extracted. It was first employed in petroleum production in 1865 when Edward Roberts, a Union Lieutenant Colonel, dropped explosive charges known as torpedoes into oil wells to increase their yield by cracking the surrounding rock and allowing the oil to pool

(American Oil & Gas Historical Society, 2021). Following the Civil War, Lt. Col. Roberts founded the first US fracking firm, The Roberts Petroleum Torpedo Company, in Titusville Pennsylvania, which continued to produce and develop fracking technologies until the early 1990s (Madrigal, 2013).

However, explosive fracturing is dangerous and produces unpredictable results, especially in the context of shale, which is characterized by high structural variability and contains highly combustible natural gas (Gandossi and Von Estorff, 2015). An alternative, non-explosive fracturing method using pressurized fluid to crack rock formations was introduced in 1949 by the Haliburton and Stanolind companies and developed throughout the 1950s, but it was not until the 1980s that the technology was used for natural gas extraction from shale (American Oil & Gas Historical Society, 2021; Palisch et al., 2010).

The 1973 OPEC oil embargo and subsequent energy crisis sparked interest in developing domestic energy sources leading to the US Department of Energy investing hundreds of millions of dollars in direct research, numerous research grants, and a full survey of US shale formations (Harper, 2008; Golden and Wiseman, 2014). In terms of the development of hydraulic fracturing, the most significant beneficiary of this massive public investment was George Mitchell who used public funds and publicly funded research to begin experimenting with hydraulic fracturing techniques in the Texas Barnett Shale formation (American Oil & Gas Historical Society, 2021; Golden and Wiseman, 2014). Throughout the 1980s, Mitchell experimented with hydraulic fracturing techniques, and in 1991, Mitchell officially partnered with the US DOE and the federally funded Gas Research Institute to research and develop the fracking fluid and specialized wellheads required for the hydraulic fracturing of shale formations (American Oil & Gas Historical Society, 2021; Golden and Wiseman, 2014). Mitchell's company, the Mitchell

Energy & Development Corporation continued improving their fracking method and technology throughout the 1990s, however they did not pursue patent protection, and by the end of the century, they had generated the technique and technology of modern fracturing, which were in the public domain, and proved their viability (American Oil & Gas Historical Society, 2021; Golden and Wiseman, 2014; Wang and Krupnick, 2013).

Mitchell's innovation was to combine 'slickwater' fracking fluid with unconventional (horizontal) drilling to maximize both the pressure of the fluid injected into the fracking well and the area of the shale that is fractured. Modern hydraulic fracking involves pumping between 1.5 million to 16 million gallons of water (averaging 4.5 million gallons per well in the Marcellus) into a shale formation to create fissures in the rock that will allow the natural gas trapped in the shale pores to pool and escape through the well (Duncan et al., 2012). However, these fissures soon collapse under the immense pressure of the surrounding rock and earth if not held open by a granular material that is injected with the fluid. This granular material, known as a propping agent or proppant, is usually sand. However, to maintain the high flow rate necessary to create the pressure needed to fracture shale, the viscosity of the water-proppant solution is reduced through the addition of chemicals (Palisch et al., 2010). The fracking fluid produced through this mixture of water, sand, and viscosity reducing chemicals is called slickwater. Slickwater is injected into a well that is first drilled vertically, and then drilled horizontally through the shale formation. Horizontal drilling allows the fracturing to occur along a greater area allowing for the fractures to reach more natural gas filled pores and a greater quantity of natural gas to be extracted as shown in Figure 4.

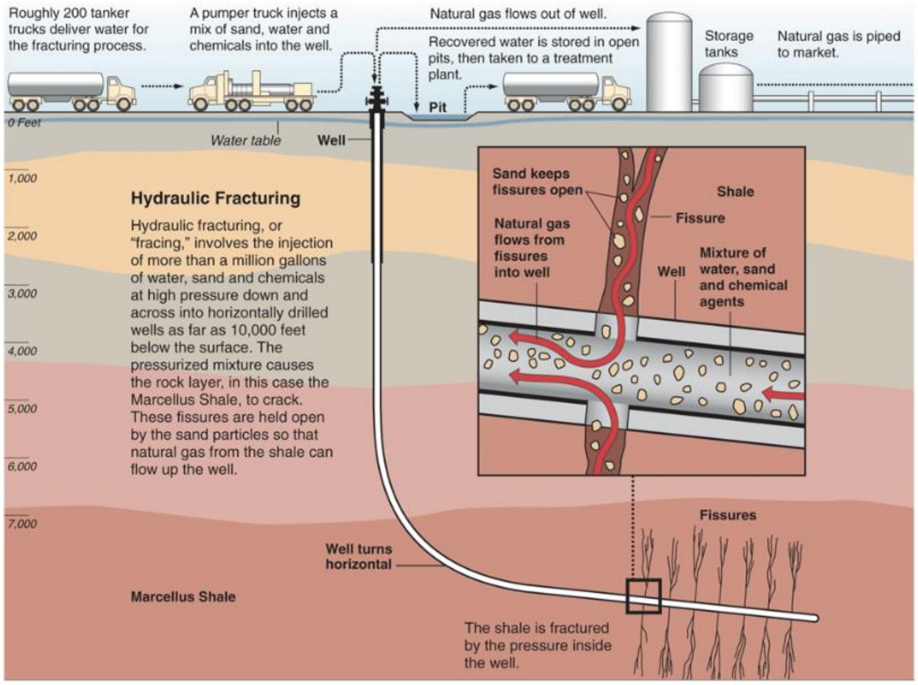


*Figure 4: Hydraulic Fracturing  Source: Belyadi, 2011*

Thus, by the year 2000, the technology needed for the hydraulic fracturing of shale had been developed and proven. However, the incentives for massive investment in hydraulic fracking did not come to exist until a combination of economic and regulatory conditions aligned in the early 2000s. First, due to declining production of conventional natural gas and a booming economy, the wellhead price (the wholesale price at the point of production) of natural gas dramatically increased in 2000-2001, nearly doubling from the wellhead price in 1998-1999, and this price continued to increase until the 2007-2008 financial crisis as shown in Figure 5 (Wang and Krupnick, 2015). Second, the passage of the 2005 U.S. Energy Policy Act exempted hydraulic fracking from regulation under the Safe Drinking Water Act of 2005, Underground Injection Control, the Clean Water Act, the Hazardous Materials Transportation Act, and the Emergency Planning and Community Right to Know Act, which abolished mandatory disclosure of the contents of fracking fluids, further lowering the costs of fracking (Scanlan, 2017; Susko, 2017; US EPA, 2015). The combination of elevated wellhead prices, lowered regulatory costs, and the existence of readily available, proven technologies led to massive investment in natural gas development, and the fracking boom began.

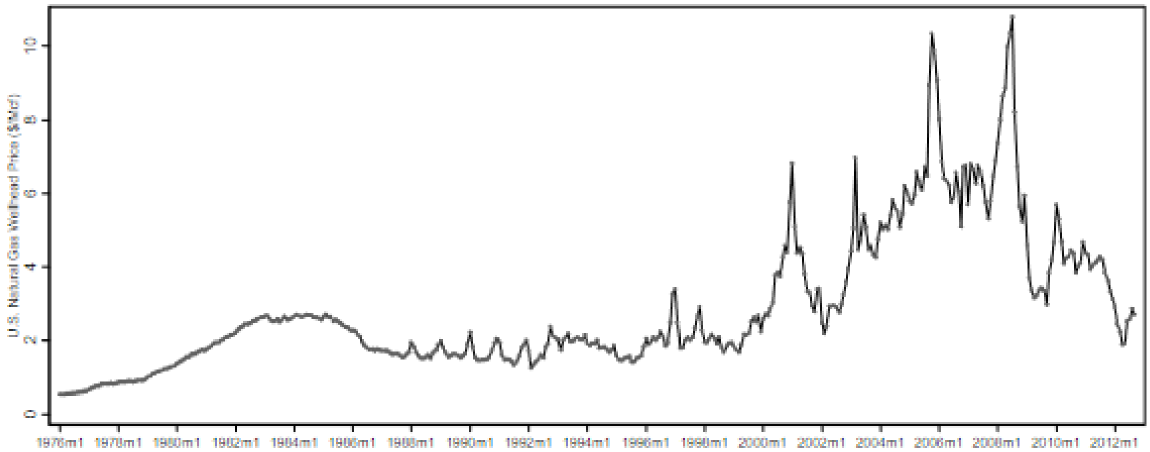

*Figure 5: US Natural Gas Wellhead Price, 1976-2012 Source: US EIA*

## C. The Pennsylvania Fracking Boom

Range Resources drilled the first hydraulic fracking well in Washington County, Pennsylvania in 2003, and began commercial natural gas production from this well in 2005 (Belyadi, 2011; Stedman, 2012). From 2005 onwards, there has been a steady addition of new, unconventional natural gas wells per year in the Marcellus Shale region, with thousands of new wells drilled each year since 2008 as shown in Figure 6. While the number of wells drilled per year in Pennsylvania alone is significantly less, it has exceeded more than 500 wells per year since 2009 and exceeded more than 1000 new wells per year between 2010-2014 as shown in Figure 7.

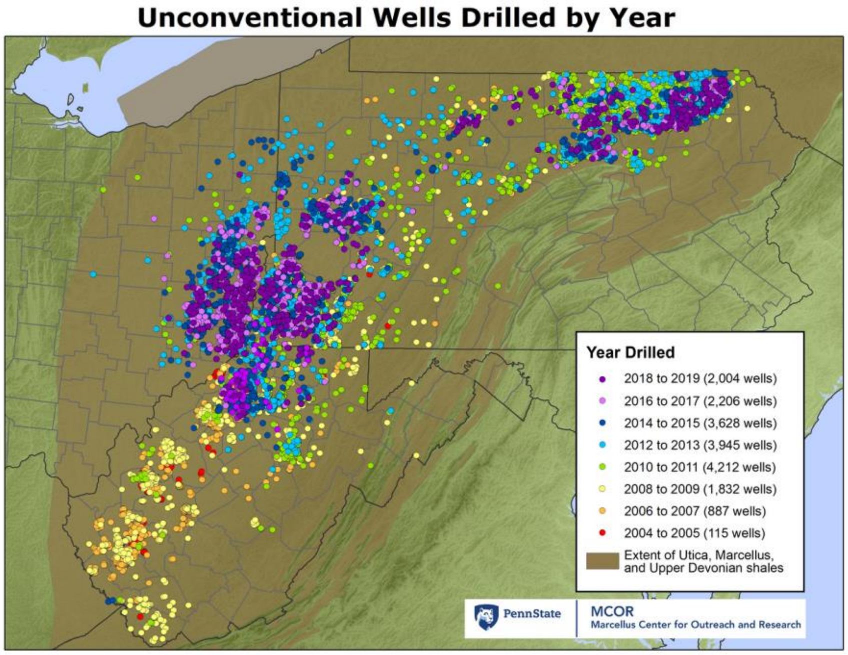


*Figure 6: Marcellus Unconventional Wells Per Year. Source Marcellus Center for Outreach and Research, 2020: http://www.marcellus.psu.edu/resources-maps-graphics-videos.html*

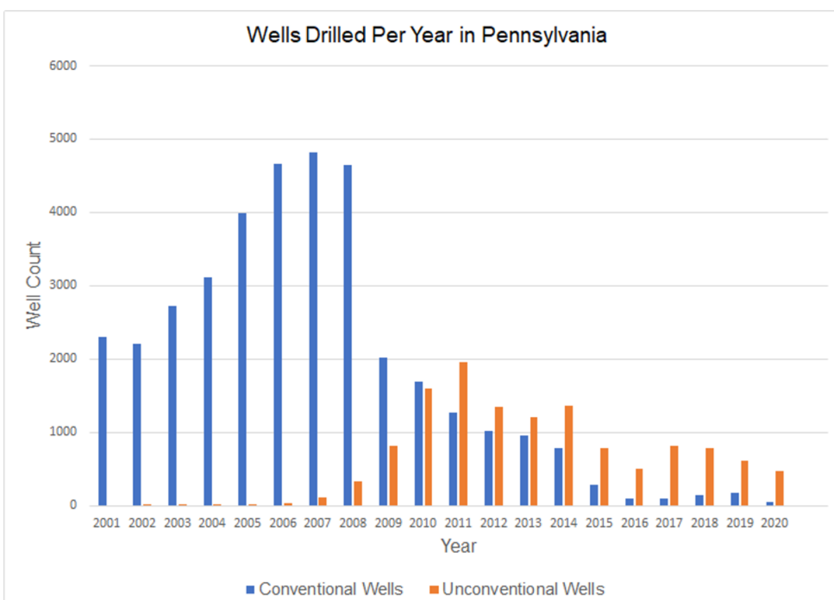


*Figure 7: New Natural Gas Wells Per Year in PA. Source: Fractracker Alliance, 2021: https://www.fractracker.org/2021/05/pennsylvania-conventional-well-map-update/*

# CHAPTER III

# THE BOOM-CRIME RELATIONSHIP AND THEORIES OF CRIME

## A. The Boom-Crime Relationship

The term ‘boomtown’ has been used to describe the sudden population and economic expansions that communities experience due to the discovery of an exploitable natural resource or innovation that allows a natural resource to be extracted for at least 100 years, and the association between natural resource booms and crime has been observed for even longer. For example, as early as 1921, historian Hermann Hagedorn described the town of Medora, North Dakota’s as a “boomtown,” and reported that during its 1884 cattle boom, it became a chaotic place full of the “outcasts of society, reckless, greedy, and conscienceless; fugitives from justice with criminal records, and gunmen who lived by crooked gambling and thievery of every sort” (Hagedorn, 1921). Contemporary accounts of the 1849 California gold rush and the 1890s Yukon gold rush describe a similar, chaotic, and dangerous milieu (Ruddell, 2017). However, while the relationship between rapid economic and population growth and crime has long been observed, social theorists did not propose a systematic explanation of this effect until the 1940s.

## B. Social Theories of Crime

### 1 Social Disorganization

Social disorganization is one of the most cited social theories used to explain the relationship between boomtowns and crime. Sociologists Shaw and McKay developed the theory of social disorganization in the 1940s to explain spatial and temporal patterns in juvenile delinquency in Chicago (McMurtry et al., 2008;  Stratesky et al., 2018). They observed a correlation between high rates of population turnover and high rates of juvenile delinquency and theorized that rapid changes in population diminish the ability of communities to informally moderate behavior through community institutions and relationships (Stratesky et al., 2018). The theory further suggests that rapid population growth or change can increase feelings of suspicion, increase anonymity, increase competition for resources, and reduce familiarity with and concern for neighbors, all of which increase the propensity for an individual to engage in antisocial behavior (Ruddell, 2017).

Social disorganization theory was not directly applied to boomtowns until the 1970s, when the energy crisis spurred interest in domestic fossil fuel production and renewed interest in boomtown research (Stedman et al., 2012). Two related concepts were developed and incorporated into the theory. First, the theory of social disruption was developed to describe how the rapid population influx experienced by boomtowns creates two distinct populations, long-term residents and newcomers, which disrupt long-standing social relationships and power structures, increasing stress and further reducing informal social controls (Ruddell, 2017). Finally, environmental sociologist William Freudenburg expanded the theory of social disorganization by adding to it the concept of the density of acquaintanceship. Freudenburg noted that the small, rural communities that are most affected by natural resource booms and most likely to be transformed into boomtowns are defined by residential stability and a high density of acquaintanceship. Prior to the boom, residents intended to be long-term community members, were active in the community, and had a relatively high amount of contact with each other. The pre-boom high density of acquaintanceship encouraged watchfulness, care for one's acquaintances, and the types of socialization that deter antisocial behavior. Rapid population growth decreases the density of acquaintanceship, thus reducing the attitudes and behaviors that minimize crime (Ruddell, 2017).

## 2 Masculinity and the Composition of Fracking Labor

The demographics of fracking labor may directly have a causal impact on crime and antisocial behavior. In 2020, nearly 86% of all people employed in oil and gas extraction were male, and nearly 57% were younger than 44 years old with 30% being younger than 35 (US Bureau of Labor Statistics, 2021). These statistics are likely to skew even younger and more male for people employed in fracking. Migrants to fracking have been shown to be almost totally in the age range of 25-44 years old, male, unmarried, and are more likely to be high-school dropouts or ex-convicts than the long-term residents of the communities they migrate to (Archibold, 2014; Picker, 2015; Wilson, 2020). Finally, there is anecdotal evidence to suggest that a machismo culture in which aggression is esteemed and certain drug abuse, mostly alcohol and stimulants, is encouraged is dominant among fracking labor (Ruddell, 2017 ;Stretesky and Grimmer, 2020). These statistics suggest that the fracking workforce may be a population statistically more likely to engage in illicit activities.

FBI Uniform Crime Reporting data indicates that males commit more than 80% of all violent crime and more than 60% of all property crime (University of Minnesota, 2015). Males are also more likely to use almost all types of illicit drugs, have higher rates of drug and alcohol dependency, and are 7 times more likely to hire sex workers than females (University of Minnesota, 2015; NIDA, 2021). High-school dropouts are more likely to engage in certain types of crime including assault, larceny, and drug-related crimes (Maynard et al., 2015). According to FBI data, more than 40% of all crimes are committed by people between 15-24 years old (University of Minnesota, 2015). A negative relationship between marriage and crime especially among men has been established by a growing body of literature (Skeearhamar et al., 2015). There is also evidence that prior incarceration may increase the propensity for a person to commit a violent crime (Harding, 2019). Finally, non-local labor does not have existing ties to the communities in which they work, and therefore bear a low social cost to committing crime, and this could be especially true for transient labor (Gourley and Madonia, 2018). As such, it is plausible that fracking increases crime and antisocial behavior simply through the immigration of a population more likely to engage in crime and antisocial behavior.

### C. Economic Theories of Crime and Boomtowns

#### 1 Rational Choice

Gary Becker developed his now canonical economic model of criminal activity and its social cost in 1968. In short, Becker contends that individuals make rational decisions whether to commit crimes based on the expected utility they attribute to the illegal action. A potential criminal's expected utility from crime is a function of the direct utility she would receive from the illegal act, any profit to be made from the crime, the chance of being caught, the potential punishment if she is convicted of the crime, and her opportunity cost of pursuing the crime rather than pursuing an alternative, legal activity. If her expected utility from an illegal activity exceeds her expected utility from legally sanctioned alternatives, she will commit the crime (Becker, 1968). A pertinent implication of this perspective on crime is that as returns to legal activities increase, crime should decrease as the opportunity cost of illegal activities increases and individuals substitute towards legal alternatives. It is plausible that when a local economy grows due to a natural resource boom, the potential returns from legal employment grow, increasing the opportunity cost of crime and decreasing crime as individuals substitute away from illegal activities and towards legal employment (Street 2020). However, if the rapid increase in population outpaces increases in the police force, the chance of being caught may decrease as there are fewer police officers per person in the community, which would increase the expected utility of crime, and could mitigate decreases in crime due to rising opportunity costs depending on the utility function.

### 2 Increases in inequality

The fracking boom may increase crime through other economic channels. Since households benefit from the fracking boom disparately, with some households receiving direct income and royalties from fracking and others not, fracking could increase inequality, which has been shown to be positively associated with higher crime rates (Mejia and Restrepo, 2016; Komarek, 2018). There is evidence that the introduction of fracking in Pennsylvania has increased inequality due to increases in royalty income for mineral rights holders exceeding employment and compensation impacts (Hardy and Kelsey, 2015).

### 3 Increased Demand for Illegal Goods and Services

Increased disposable income due to fracking may directly lead to crime by increasing demand for illicit goods such as drugs and prostitution or increasing demand for goods that are complements to crime such as alcohol (Street, 2020).

### 4 Dutch Disease

Natural resource booms may exacerbate existing poverty and inequality for some through the phenomenon of Dutch Disease. The classic model of Dutch Disease was first articulated in 1984 by Australian economist Warner Corden who demonstrated how a resource boom could cause a sudden increase in demand for labor in the extractive industry, which shifts labor towards the booming sector and away from other industries, known as the lagging sector, which then contract (Corden, 1984). The corresponding increase in unemployment lowers the opportunity cost of crime, and increasing inequality also increases crime. Dutch disease may especially affect agriculture and manufacturing,, and if the contraction of these industries decreases a community's tax base, it could result in reduced social services, which may increase the expected utility of crime, thereby increasing crime (Stretesky and Grimmer, 2020).

# CHAPTER IV

# LITERATURE REVIEW

The fracking boom has reinvigorated interest in boomtowns and the boomtown effects, resulting in a growing literature investigating the relationship between fracking and a variety of social outcomes including crime. An increasing number of these studies employ econometric methods to establish a causal connection between fracking and crime. In their 2020 literature review, Stretesky and Grimmer summarize 25 studies demonstrating a causal relationship between the introduction of hydraulic fracking and increased crime rates published between 2005-2019. The unit of analysis for the majority of these studies is the county-year, though one studied employed county-month. As the independent variable, the majority of studies employed either the amount shale gas production within a county or the number/density of active wells within the county. Of the significant relationships identified by these studies, 9 found a positive relationship between fracking and violent crime, 7 found a positive relationship between fracking and crimes against women, 7 found a positive relationship between fracking and property crime, and 4 found a positive relationship between fracking and total crime. Only 3 found a significant negative relationship between fracking and total crime. There were no other significant negative relationships identified.

Apart from the studies summarized by Stratesky and Grimmer, there have been several recent studies, which have employed econometric methods to investigate the relationship between fracking and crime:

Price et al. (2014) use a fixed-effects methodology to examine the relationship between fracking and various social outcomes in Pennsylvania, Ohio, and West Virginia. Their analysis is conducted at the county-year level between 1999-2012 and uses the number of wells in a county as the treatment variable. They focus their analysis on high-drilling counties defined as counties in which more than 400 wells have been drilled. They find a statistically significant increases in violent crime (17.7%), property crime (10.8%), drug abuse (48%), sexually transmitted infections (24-27%), and motor vehicle fatalities (27.8%). However, they did not find evidence of significant population growth, suggesting that either the economic effects of fracking alone generate crime among the existing population, in-migration and out-migration from fracking communities is balanced, or a transient population not captured by census population estimates is responsible for the elevated crime rates.

James and Smith (2017) employ a difference-in-difference design to investigate the relationship between shale gas production and crime in Arkansas, Colorado, Louisiana, Montana, North Dakota, New Mexico, New York, Ohio, Oklahoma, Pennsylvania, Texas, West Virginia, and Wyoming. Their analysis is conducted at the county-year level for the years 2000-2013, and they define treatment as being located in a shale formation during a fracking boom. They find a statistically significant positive relationship between shale gas development and several types of crime including aggravated assault (10.8%), simple assault (7.4%), larceny (8.7%), rape (2.8%) and automotive crime2 (13.3%). They further investigate whether the increase in crime rates can be attributed to changes in age or demographics. They do not find a statistically significant relationship. However, they rely on census data to track demographic changes, and it is possible that the types of short-term demographic changes that could result from the influx of workers required to drill and frack a well are not adequately captured by census data. However, they do find evidence that a disproportionate number of prior criminals (specifically registered sex offenders) move to fracking boom towns.

Komarek (2018) also uses a difference-in-difference design to investigate the relationship between fracking and crime. His unit of analysis is county-year for the years 2004-2012, but he confines his analysis to counties in New York and Pennsylvania that lie over the Marcellus shale formation. He treats the 2008 New York moratorium on fracking as creating a natural experiment. Following 2008, New York Marcellus counties serve as a control group for their Pennsylvanian counterparts, which receive the treatment defined as new fracking wells. Komarek identifies statistically significant positive relationships between fracking and violent crimes such as rape and assault, but not property crimes.

Stretesky et al. (2018) use a fixed effects methodology to study the effect that oil and gas development has had on crime rates in the United Kingdom. Their analysis is conducted at the authority-year level, and they define treatment as the number of active wells. Generally, they find that each additional well is associated with a 1.5% increase in violent crime. Like Komarek (2018) they do not find a statistically significant relationship between fracking wells and property crime. However, when they limit their analysis to the most intensely treated authorities, they find that each additional well is associated with a 4.9% increase in violent crime and a 4.9% increase in property crime.

Lim (2018) uses a multiple regression methodology to investigate the effect that oil production has had on crime in the Bakken shale formation, which stretches between Montana and North Dakota. Interestingly, unlike the majority of other studies, while she finds that shale gas production is positively related to property crimes including burglaries, larcenies, and motor vehicle theft, she did not find statistically significant evidence that shale gas production is related to an increase in violent crimes such as murder, rape, and armed robbery. However, she does find statistically significant evidence that aggravated assaults are positively related to fracking.

Street's (2020) analysis is unique in that she disaggregates the populations of North Dakota counties to examine the impact that fracking has had on crimes committed by long-term residents. Her unit of analysis is at the household-year level and uses a difference-in-difference methodology with two treatments: Being within a county following the leasing of land for the drilling of fracking wells and being in a county during production of natural gas from fracking wells. She finds that both treatments lead to a significant decrease in overall crimes committed by long-term residents. Following leasing, she identifies a 14% reduction in crimes committed, and the reduction continued during the production period. Her results could indicate that the positive relationships between fracking and crime identified in other studies are driven entirely by the in-migration of fracking labor.

There is also a growing literature establishing causal relationships between fracking and other negative social outcomes including increases in STIs and prostitution (Beleche and Cintina, 2018; Komarek and Cseh, 2017), emergency room visits (Ward and Price, 2014), and motor vehicle accidents (Mason et al., 2015; Ruddell, 2017).

# CHAPTER V

# HYPOTHESIS AND ECONOMETRIC APPROACH

## A. Hypothesis

The unique logistics of fracking differentiate it from traditional resource booms. Fracking is most labor intensive during the initial construction of the pad and drilling (spudding), which lasts from 4-8 weeks (Lendel, 2014). The average well in the Marcellus requires over 400 workers during this phase, but after spudding only a dozen workers per year are required to maintain a well, which can produce gas passively for a decade (Beleche & Cintina, 2018; Lendel, 2014; Komareck, 2018). The majority of the workforce during spudding is non-local and transient, and housed in labor camps apart from local communities (Beleche & Cintina, 2018; Lendel, 2014; Ruddell, 2017; Wrenn etl al., 2015).

It is therefore plausible that fracking impacts crime through two distinct channels. First, the immediate influx of a temporary, majority young, male workforce without ties to the community could create a spike in crime rates either due to crimes committed by members of the workforce itself or crimes that result from tensions between the workforce and the long-term residents of the community. Second, the economic impact of fracking may cause some in-migration of labor resulting in social disruption and could exacerbate inequality and perhaps unemployment in some sectors. However, the transient workforce would not contribute to long-term changes in the economic conditions and social milieu of the communities. As such, the impact of spudding should be distinct from the impact of long-term shale gas development.

## B. Econometric Approach

The following specification estimates the relationships between initial well development and crime and long-term shale gas development and crime:

$$\ln(C_{cmy}) = \alpha + \beta_1(NewWellRate_{cmy}) + \beta_2(ActiveWellRate_{cmy-1})$$
$$+\gamma_{cy} + \delta_c + \zeta_c + \in_{cmy} \tag{1}$$

where $C_{cmy}$ is a crime rate (offences per 1000 people) in county *c* during month *m* and year *y*. This study is more concerned with the differentiation between the types and intensity of crime affected by the two distinct treatments, therefore, to make the changes in the intensity of the effect more apparent, the natural log of the dependent variables is used so that the estimates may be interpreted as percent changes. It should be noted that crimes are relatively rare occurrences, especially violent crimes. As such, even a small change in the quantity of crime can result in a large percent change in the crime rate.

$\beta_1$ and $\beta_2$ are the coefficients of interest.$NewWellRate_{cmy}$ is the proxy for spudding and is defined as the number of new wells per 1,000 people in county *c* during month *m* and year *y*. $ActiveWellRate_{cmy-1}$ *is* the number of active wells per 1,000 people in county *c* during month *m* and the previous year, *y-1*, respectively. $\beta_1$ captures the impact that new well development has on crime rates, and $\beta_2$ captures the impact that long-term fracking gas production has on crime rates. The separation of new wells and active wells allows us to identify if new well development and fracking gas production in general have heterogenous effects on crime.

$\gamma_{cy}$ is a vector of socioeconomic controls at the county-year level. $\delta_c$ is a vector of county fixed effects. $\zeta_c$ is a linear time trend. $\in_{cmy}$ is a random error term.

# CHAPTER VI

# DATA

Well data was obtained from The Carnegie Museum of Natural History's Pennsylvania Unconventional Natural Gas Wells Geodatabase (Whitacre and Slyder, 2021). This dataset contains well spud dates (the date when drilling commences) for unconventional natural gas wells. The well data is at latitude-longitude-day level, but in order to merge this dataset with crime data, wells were aggregated to the county-month-year level. This paper uses well data from 2003 when the first fracking well was drilled in Pennsylvania until 2017. The counts and rates for wells prior to 2003 are 0. Active wells in a county are calculated by summing all prior new wells and subtracting all plugged wells.

There is considerable spatial variation in well location due to the geography of the Marcellus shale as shown in Figures 3 and 6. There is also considerable temporal variation and variation in the intensity of fracking due to the disparate spud dates as shown in Figure 8. The vagaries of the distribution of well-locations and well spud dates provide exogenous variation that can be exploited to identify the relationship, if any, between fracking and crime-rates.

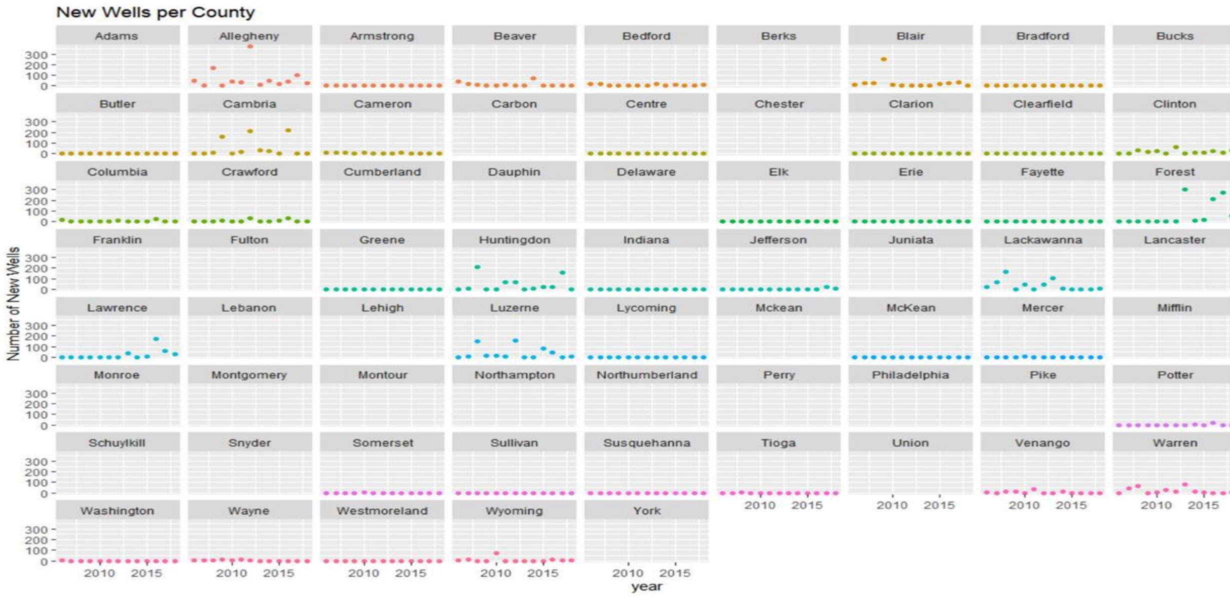


*Figure 8: New Wells per County in PA*

Crime data was obtained from the FBI's Uniform Crime Reporting (UCR) system. The UCR contains counts of crimes as reported by local agencies aggregated to the month-county level. Crime rates defined as crimes per 1000 people are calculated by dividing the crime count by the population and multiplying by 1000. This paper uses the aggregate FBI Index Crime rates, as well as rates for nine individual crimes. Violent Index Crimes include aggravated assault, rape, murder, and robbery. Property Index Crimes include arson, burglary, larceny-theft, and motor vehicle theft. Total Index Crimes include all Violent Index Crimes and Property Index Crimes. Figures a1-a5 in the appendix present the evolution of the mean values for these crime rates between 1999-2017 for both fracking and non-fracking counties, with a fracking county defined as a county which hosts a fracking well at any point between 1999-2017.

However, reporting to the UCR is at the discretion of local law enforcement agencies, and not all criminal complaints result in the creation of a report. For example, if local law enforcement chooses to issue a warning for a criminal complaint, it will not be included in the UCR. Furthermore, prior research has established that police departments receive a substantial increase in call volume during fracking booms, and since expansions in policing often lag-behind the onset of the boom, police departments sometimes lack the manpower and resources to respond to every call for police services (Archibold etl al., 2014; Ruddell, 2011; Ruddell, 2017). As such, it is likely that boomtown crime is underrepresented in the UCR. Therefore, estimates drawn from this data should be considered lower bounds.

As socioeconomic controls, mean county income adjusted for inflation and the unemployment rate were selected due their recognition by the FBI as variables affecting crime (US FBI, 2012). Additionally, the Sex-Ratio (Male population/ Female Population), and the percentage of the population comprised of males between 15-24 years old were chosen due to an abundance of scholarship establishing their causal relationship to crime as reviewed in section 3.2.2. Socioeconomic controls include population estimates obtained from The Census Bureau's Population Estimates Program, unemployment data from the US Bureau of Labor Statistics, and County Economic Profiles obtained from the US Bureau of Economic Analysis. All controls are available only at the county-year level. For each year, a constant value is used for each socioeconomic control rather than interpolating between years to obtain monthly estimates.

Tables 1 and 2 presents summary statistics for all independent variables, crime rates, counties and years used in this analysis. Tables a1-a8 in the appendix provide summary statistics for the years 1999, 2000, 2010, and 2017 specifically.

Table 1: Summary Statistics

| | Variable | Mean | Std. dev. | Min | Max | Median |
|---|---|---|---|---|---|---|
| Fracking | | | | | | |
| | Number of Active Wells | 67.14 | 202.79 | 0 | 1628 | 0 |
| | Population | 369568.75 | 411972 | 4509 | 1134335 | 165984 |
| | Unemployment Rate | 6.29 | 1.49 | 2.7 | 14.3 | 6 |
| | Mean Real Income | 26.55 | 5.38 | 6.44 | 80.86 | 24.92 |
| | Sex-Ratio M/F | 0.95 | 0.08 | 0.87 | 2.25 | 0.93 |
| | Per. Male 15-24 | 0.08 | 0.02 | 0.06 | 0.19 | 0.07 |
| Non-Fracking | | | | | | |
| | Population | 378775.11 | 198719 | 12380 | 1376074 | 388924 |
| | Unemployment Rate | 5.32 | 1.63 | 2.6 | 13.4 | 4.9 |
| | Mean Real Income | 34.88 | 8.86 | 18.24 | 55.19 | 32.31 |
| | Sex-Ratio M/F | 0.95 | 0.04 | 0.84 | 1.28 | 0.95 |
| | Per. Male 15-24 | 0.08 | 0.01 | 0.06 | 0.11 | 0.08 |

Table 2: Crime Rate Summary Statistics

| | Variable | Mean | Std. dev. | Min | Max | Median |
|---|---|---|---|---|---|---|
| Fracking | | | | | | |
| | Total Crime | 1.7 | 1.36 | 0 | 12.15 | 1.38 |
| | Property Crime | 1.18 | 1 | 0 | 7.75 | 0.91 |
| | Violent Crime | 0.19 | 0.29 | 0 | 9.19 | 0.1 |
| | Total Assault | 0.5 | 0.59 | 0 | 14.98 | 0.34 |
| | Aggravated Assault | 0.14 | 0.23 | 0 | 3.38 | 0.03 |
| | Simple Assault | 0.37 | 0.51 | 0 | 13.59 | 0.2 |
| | Murder | 0 | 0.02 | 0 | 0.7 | 0 |
| | Manslaughter | 0 | 0 | 0 | 0.23 | 0 |
| | Robbery | 0.04 | 0.09 | 0 | 1.79 | 0 |
| | Rape | 0.02 | 0.07 | 0 | 9.03 | 0 |
| | Larceny | 1.18 | 0.98 | 0 | 29.29 | 0.93 |
| | Burglary | 0.28 | 0.33 | 0 | 6.87 | 0.2 |
| | Motor Veh. Theft | 0.08 | 0.13 | 0 | 3.97 | 0 |
| Non-Fracking | | | | | | |
| | Total Crime | 2.06 | 1.5 | 0 | 29.9 | 1.71 |
| | Property Crime | 1.56 | 1.14 | 0 | 27.07 | 1.29 |
| | Violent Crime | 0.18 | 0.32 | 0 | 11.94 | 0.09 |
| | Total Assault | 0.44 | 0.52 | 0 | 12.69 | 0.27 |
| | Aggravated Assault | 0.12 | 0.25 | 0 | 5.21 | 0.03 |
| | Simple Assault | 0.31 | 0.42 | 0 | 12.37 | 0.18 |
| | Murder | 0 | 0.01 | 0 | 0.97 | 0 |
| | Manslaughter | 0 | 0 | 0 | 0.49 | 0 |
| | Robbery | 0.04 | 0.11 | 0 | 1.36 | 0 |
| | Rape | 0.02 | 0.07 | 0 | 11.69 | 0 |
| | Larceny | 1.23 | 0.95 | 0 | 27.07 | 1 |
| | Burglary | 0.24 | 0.27 | 0 | 8.57 | 0.18 |
| | Motor Veh. Theft | 0.09 | 0.15 | 0 | 3.27 | 0 |

# CHAPTER VII

# RESULTS AND DISCUSSION

Tables 3-5 report the results of (1). For each specification, the dependent variables are crime rates (crimes/ 1,000 people) and the independent variables of interest are the well rates New Wells/ 1,000 people and 1-year lagged Active Wells/1,000. Heteroskedastic-robust standard errors clustered at the county level are reported in parentheses. Significance levels are reported for the 5% (*), 1%(**) and 0.1%(***) levels. The natural log of the well rates was taken, so the coefficients can be interpreted as the percent changes in crime rates.

The results suggest that the initial construction and drilling of fracking wells and the long-term presence of fracking affect crime in strikingly dissimilar ways in terms of both type of crimes affected and intensity of the effect. The significant, positive coefficients for lagged active wells indicates that fracking activity does in general increase total crime, property crime, and violent crime, which aligns with previous research.

However, the novelty of this study is the separation of new and existing fracking wells, and the results provide insights into the channels by which fracking affects crime. While existing wells affect a broader range of crime, and their effects are more statistically significant, the magnitude of the significant increases in crime attributed to new wells is uniformly much greater. Furthermore, with the exception of motor vehicle theft, new wells mainly influence violent crime rates. These results suggest that counties experience the greatest increases in violent crime during the initial construction and drilling of wells. However, since property crimes are more prevalent, the long-term effect of fracking is a general increase in crime rates driven by increases in property crime and lower increases in violent crimes.

In all significant cases, the magnitude of the estimates for new wells is approximately 2,000-3,000% greater than the estimates for existing wells. This may be due to the intensity of the influx of fracking labor during the drilling period. Since much of this labor is non-local and transient, a potential narrative is that during the 4-8 week construction and drilling periods, crime rates within a county are elevated by crimes committed by fracking labor or crimes that occur due to conflicts between local residents and fracking labor. Street (2020) found no significant increases in crime by long-term residents in North Dakota fracking boomtowns, and while my study cannot distinguish between crime committed by transient or in-migrant fracking labor and long-term residents, the large significant increases in crime during the initial drilling period is consistent with her finding that the fracking-boom-crime relationship is driven by the influx of fracking labor. Furthermore, the introduction of new fracking wells has the greatest impact on violent crime, which suggests that the perpetrators are likely young males due to majority of violent crime being committed by young males. Fracking labor is almost entirely young and male, so it is not inconsistent that the sudden influx of a transient, largely young, male population could result in increases in violent crime.

Increases in crime due to existing fracking wells may be due to any of the mechanisms discussed in Section 3 and is likely due to a combination of several of these mechanisms. However, as no negative relationships were found, it is unlikely that fracking increased the opportunity cost of crime to the point that potential criminals would choose legal activities over illegal activities as Becker's model would suggest. While Street's (2020) finding that crime rates among long-term residents in North Dakota fell, may not hold in the Pennsylvanian context, if it does, it would suggest that the other social and economic mechanisms discussed may not hold since each of these mechanisms should affect long-term residents and increase their propensity for crime. As such, the results found in this study and Street (2020) may suggest that crime associated with the introduction of fracking is largely a function of the influx of fracking labor, and that this is most intense during the initial construction and drilling period.

The finding that violent crimes are most increased during the initial construction and drilling period has important policy implications. This finding suggests that communities should prepare for an increase in violent crime during the spudding of wells. Since land-leases and drill dates are publicly available prior to construction and drilling, this is feasible. However, expansions in policing lag behind the introduction of fracking, and the often-poor, rural communities in which fracking wells are most often introduced frequently lack the resources to expand policing and public services (Ruddell, 2017). Since communities will not benefit from tax-revenues produced by fracking until after production has begun, it may be hard or impossible to sufficiently expand policing and public services prior to the introduction of fracking wells. As such, it may be necessary for communities expecting fracking to develop alternative financing strategies to prepare for fracking development.

Ruddell (2017) notes that local governments are often ill-prepared and that local communities often lack the resources to manage booms. One potential strategy he suggests is for local governments at the town, city, and county-level to collaborate to solve boom—related problems. Since nearby communities likely face elevated incidents of crime without receiving any of the tax-income from fracking, this strategy has the benefit of more equitably distributing the social costs of fracking. Another option is for state government to help fund increases in local police and public services. Rabe & Hampton (2015) report that in 2015, the state government of North Dakota approved $1.1 billion in ‘surge’ funding for local infrastructure repair in oil-producing areas. Perhaps states could provide a similar infusion of funds to local governments for police and public safety improvements. However, as I have shown in this study, to mitigate the most intense and harmful increases in crime, the funds would have to be provided prior to the development of fracking wells.

Table 3: Regression Results: Total Crime Rates

| | (1)<br>Total Crime | (2)<br>Total Property | (3)<br>Index Violent |
|---|---|---|---|
| New Wells/1000 | -0.00774 | 0.0330 | 0.248* |
| | (0.0625) | (0.0834) | (0.123) |
| Lag Active Wells/1000 | 0.00680** | 0.0111*** | 0.0130*** |
| | (0.00215) | (0.00240) | (0.00365) |
| Unemployment | 0.0222*** | 0.0248*** | 0.0125** |
| | (0.00406) | (0.00397) | (0.00390) |
| Mean Income | 0.00677 | 0.00486 | -0.00380 |
| | (0.00550) | (0.00528) | (0.00489) |
| Sex-Ratio m/f | -0.366 | -0.489 | 0.713 |
| | (0.455) | (0.626) | (0.619) |
| % Male 15-24 | 7.848** | 9.221** | 1.821 |
| | (2.799) | (2.834) | (3.200) |
| Lin Time | -0.00132*** | -0.00128*** | 0.000412 |
| | (0.000194) | (0.000205) | (0.000240) |
| Constant | 0.0654 | -0.116 | -1.951** |
| | (0.465) | (0.621) | (0.586) |
| Observations | 208800 | 208800 | 208800 |

(Natural Log Dependent Variable,County FEs, Robust Standard Errors Clustered at County Level)
Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4: Regression Results: Violent Crime Rates

| | (1) Total Assault | (2) Aggravated Assault | (3) Simple Assault | (4) Murder | (5) Manslaughter | (6) Robbery | (7) Rape |
|---|---|---|---|---|---|---|---|
| New Wells/1000 | 0.114 | 0.307* | 0.126 | 0.373* | 0.376* | 0.352* | 0.321* |
| | (0.0841) | (0.122) | (0.0938) | (0.162) | (0.162) | (0.161) | (0.151) |
| Lag Active Wells/1000 | 0.00324 | 0.0135*** | 0.00175 | 0.0120** | 0.0120** | 0.0134** | 0.0110** |
| | (0.00215) | (0.00383) | (0.00237) | (0.00408) | (0.00407) | (0.00412) | (0.00357) |
| Unemployment | 0.0147*** | 0.0130** | 0.0188*** | 0.0214*** | 0.0216*** | 0.0206*** | 0.0192*** |
| | (0.00357) | (0.00414) | (0.00380) | (0.00425) | (0.00424) | (0.00442) | (0.00403) |
| Mean Income | 0.00211 | -0.00638 | 0.00240 | -0.00874 | -0.00873 | -0.00634 | -0.00683 |
| | (0.00305) | (0.00540) | (0.00315) | (0.00621) | (0.00627) | (0.00657) | (0.00552) |
| Sex-Ratio m/f | -0.0302 | 0.687 | -0.383 | 0.296 | 0.302 | 0.312 | 0.337 |
| | (0.353) | (0.689) | (0.361) | (0.784) | (0.794) | (0.811) | (0.648) |
| % Male 15-24 | -0.136 | 0.406 | -1.472 | -3.141 | -3.191 | -0.377 | -2.993 |
| | (2.960) | (3.315) | (3.045) | (3.542) | (3.579) | (3.489) | (3.251) |
| Lin Time | -0.0000925 | 0.000559* | 0.000247 | 0.00135*** | 0.00134*** | 0.00104*** | 0.00125*** |
| | (0.000181) | (0.000260) | (0.000181) | (0.000288) | (0.000289) | (0.000295) | (0.000261) |
| Constant | -0.763* | -1.909** | -0.615 | -1.765* | -1.777* | -1.857* | -1.758** |
| | (0.341) | (0.652) | (0.369) | (0.745) | (0.755) | (0.770) | (0.615) |
| Observations | 208800 | 208800 | 208800 | 208800 | 208800 | 208800 | 208800 |

(Natural Log Dependent Variable,County FEs, Robust Standard Errors Clustered at County Level)

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

*Table 5: Regression Results: Property Crime*

| | (1) Larceny | (2) Burglary | (3) Motor Vehicle Theft |
|---|---|---|---|
| New Wells/1000 | 0.0843 | 0.160 | 0.316* |
| | (0.0847) | (0.0967) | (0.145) |
| Lag Active Wells/1000 | 0.0123*** | 0.0106** | 0.0132*** |
| | (0.00245) | (0.00361) | (0.00358) |
| Unemployment | 0.0222*** | 0.0380*** | 0.00725 |
| | (0.00389) | (0.00418) | (0.00431) |
| Mean Income | 0.00263 | 0.000190 | -0.00202 |
| | (0.00526) | (0.00422) | (0.00679) |
| Sex-Ratio m/f | -0.149 | -0.429 | 0.503 |
| | (0.599) | (0.902) | (0.854) |
| % Male 15-24 | 6.813* | 8.802** | -3.621 |
| | (2.969) | (3.175) | (3.673) |
| Lin Time | -0.000923*** | -0.000209 | -0.000508 |
| | (0.000209) | (0.000274) | (0.000320) |
| Constant | -0.417 | -1.377 | -1.483 |
| | (0.593) | (0.839) | (0.813) |
| Observations | 208800 | 208800 | 208800 |

(Natural Log Dependent Variable,County FEs, Robust Standard Errors Clustered at County Level)
Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

# CHAPTER VIII

# CONCLUSION

This paper presents a unique approach to decompose the affect that hydraulic fracturing has had on crime rates in Pennsylvania into increases due to existing fracking wells and increases due to the drilling of new wells. While a growing literature has established a positive, causal relationship between fracking and crime, the mechanisms behind this relationship have not been clearly identified. By making use of a high-resolution dataset, the natural experiment produced by the geography of the Marcellus Shale formation, and differences in the timing and intensity of fracking, this paper is able to identify distinctions in the way that the drilling of new wells affects crime compared to how long-term fracking production affects crime. The results indicate new drilling has a greater impact on crime, and especially on violent crimes. Since the initial construction and drilling of fracking wells is the most labor-intensive period of the fracking process, and since the majority of labor employed in this period is non-local, and transient, it is likely that the influx of fracking labor is the primary driver behind increases in crime, especially violent crime. This result has important policy implications for communities facing the introduction of fracking,

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