DISSERTATION

THREE ESSAYS REGARDING THE IMPACTS OF LEGALIZATION OF MARIJUANA ON HOUSING AND HISTORICAL POPULATION THEORY

Submitted by

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ABSTRACT

THREE ESSAYS REGARDING THE IMPACTS OF LEGALIZATION OF MARIJUANA ON HOUSING AND HISTORICAL POPULATION THEORY

Chapter 2 looks at the novel question of whether legal marijuana dispensaries' insufficient access to banking institutions has affected home prices in Denver County, Colorado. Presently, little research exists regarding legalized marijuana's impact on home prices in Colorado. Yet such research suggests legalization positively affects such prices (Burkhardt & Flyr, 2019) (Cheng, et al., 2018) (Conklin, et al., 2020). However, mechanisms by which marijuana legalization might affect home prices are not investigated. It is well-established that banks are unable and unwilling to do business with state-legalized marijuana dispensaries (Hudak, 2020). Hence, we hypothesize that dispensaries are investing cash in the housing market. We avail ourselves of tried-and-true hedonic modeling for such analysis. In so doing, we discover a statistically significant positive correlation between the quantity of recreational marijuana revenue generated and home prices in Denver County, Colorado. Our research is novel both in its thoroughness and accuracy of the data employed. To the best of our knowledge, we are the first to utilize historically accurate housing characteristics and unique economic controls in the analysis of marijuana and home prices in Denver, Colorado (Burkhardt & Flyr, 2019) (Cheng, et al., 2018) (Conklin, et al., 2020). Additionally, our study appears to represent the first consideration of implications arising from the juxtaposition of state vs. federal legal status of marijuana. As such, our research holds insights for policymakers.

Chapter 3 resumes our investigation of the possible implications of legalized marijuana for housing. Specifically, Denver County home resale probabilities and any associations they might have with marijuana revenue generated. Research has presented evidence that there exists a distinct possibility of dispensaries investing in the Denver housing market (Cheng, et al., 2018) (Rasmussen, 2021). Navarro (2013) and Seefried (2019) suggest that if dispensaries are purchasing houses, it may be for money laundering purposes. However, there is reason to believe that dispensaries have incentives to retain purchased homes for either legitimate rental purposes or more nefarious grow house uses (Schaub, 2016) (Snowden, 2020). To investigate such possibilities, we employ both logit and probit probability models. Such models are used to determine any potential association between changing amounts of legal marijuana revenue and Denver home resale probabilities. We find a statistically significant rise in property resale

rates associated with increased recreational marijuana revenue. Thus, our results fit the type of money laundering activity discussed by Navarro (2013) and Seefried (2019). Consideration of the impacts of the legalization of marijuana on home resale probabilities appears absent in the literature. Thus, our work has import for policymakers. In particular, there are implications for affordable housing availability. Together with Cheng, et al. (2018) and Rasmussen (2021), our findings bode ill for Denver County affordable housing. This is especially true as marijuana demand continues to grow while banking access remains largely absent.

Our final chapter considers the Marquis de Condorcet's six assumptions on population growth. Such a model of population development is presented in *Esquisse d'un Tableau Historique des Progress de L'Esprit Humain*. In addition, we examine the original principles and outcomes of the Malthusian population model. Such an undertaking is done to discover what conclusion Malthus' model would arrive at had the views of Condorcet been incorporated. Another important aspect of our work is investigating why Malthus's essay disagreed with the Marque de Condorcet's propositions on population. Finally, we conclude our efforts by examining empirical and historical scholarly inquiry regarding which of the population models history favored. To our knowledge, only the work of Winch (1996) comes close to our investigation. However, Winch (1996) presents a hypothetical meeting of Malthus and Condorcet, intended to discuss general differences and common ground these men possessed. However, Winch (1996) fails to consider implications for the Malthusian population model of Condorcetian population theory. Thus, our research is innovative in discovering Malthus as a man of his times and Condorcet as a scryer of the distant future of population growth.

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DEDICATION

To

My late mother, Deborah Griffis, for her innumerable sacrifices on my behalf

My beautiful wife, Elene Chobanyan, who supports and inspires the best in me every day

And my daughter Katrina Rasmussen, for being my bright light on dark days

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CHAPTER 1-INTRODUCTORY OVERVIEW

Housing and population: the two are often intertwined. As populations and their tastes change, so does the demand for homes. In turn, housing availability can influence the decisions of individuals regarding marriage, parenthood, or where to settle (Mulder, 2006). This dissertation investigates issues surrounding both population and housing.

Chapter 2 looks at the novel question of whether legal marijuana dispensaries' insufficient access to banking institutions has affected home prices in Denver County, Colorado. Currently, little research exists regarding legalized marijuana's impact on home prices in Colorado. However, the three papers that do tackle the matter indicate legalization positively affects such prices (Burkhardt & Flyr, 2019) (Cheng, et al., 2018) (Conklin, et al., 2020). Yet research does not address the mechanisms by which marijuana legalization affects home prices.

We propose that owing to the federal illegality of marijuana; banks are unable and unwilling to do business with state-legalized marijuana dispensaries. Hence, dispensaries are investing their cash in the housing market. This is hypothesized to be done to avoid crime, inflationary losses, seizure, or possible money laundering. Such is suggested conceptually by Cheng, et al. (2018), Quinton (2016), Navarro (2013), and Seefried (2019). Research shows that the presence of a dispensary lowers local crime. This strongly indicates that these cash-only businesses are finding ways to move their wealth offsite (Adda, et al., 2014) (Brinkman & Mok-Lamme, 2019) (Burkhardt & Goemans, 2019) (Huber, et al., 2016). Thus, we posit that excess dispensary cash is being invested in homes, creating an exogenous demand shock that is increasing Denver housing prices. Our investigation employs hedonic modeling to tease out the potential associations between the legalization of marijuana and Denver County home prices. We have chosen to utilize hedonic specifications after the fashion of De Haan & Diewert (2013).

We find a positive, statistically significant correlation between the amount of recreational marijuana sold and home prices in Denver County, Colorado. A substantial contribution of our research is that it represents the first investigation we are aware of regarding a possible mechanism by which the legalization of marijuana might influence home prices. Additionally, we employ novel data on Denver County home sales. Such a dataset appears superior in detail to those utilized by previous research. Specifically, our data contains historically accurate housing characteristics. Such does not seem to be the case for existing studies (Burkhardt & Flyr, 2019) (Cheng, et al., 2018)

(Conklin, et al., 2020). Furthermore, our investigation appears to be the first to consider the implications of juxtaposing the legality of marijuana at the state and federal levels. Such state vs. national legality considerations seem largely absent from existing literature and could be of great value to policymakers.

Chapter 3 continues our investigation into the implications of legalized marijuana for housing. Here we consider if the marijuana revenue generated is associated with home resale probabilities in Denver County, Colorado. Cheng, et al. (2018) and Rasmussen (2021) present evidence in favor of marijuana dispensaries' potential for investing in the Denver housing market. But to what ends? Are dispensaries purchasing and reselling properties to launder their money for use in the banking system? Seefried (2019) and Navarro (2013) suggest this. Yet, it is equally probable that dispensaries are holding the properties they purchase for rental or illegal growth purposes. Schaub (2016) and Snowden (2020) respectively hint at such a possibility.

Both logit and probit modeling strategies are employed in examining the above question. Specifically, we look to see if the amount of marijuana revenue is associated with an increase or decrease in the rate at which homes resell in Denver County. We find a statistically significant rise in property resale rates associated with increased recreational marijuana revenue. This is evidence in favor of homes being resold by dispensary owners. To the best of our knowledge, we are the first to consider any associations between legal marijuana revenue and resale rates of properties. The results of our work have important implications for policymakers. Specifically, our findings are evidence in favor of possible money laundering activities, as theoretically discussed by Navarro (2013). Further, Cheng, et al. (2018)'s research indicates that such a trend would be especially true for low to middle-value homes. Thus, our work portends possible affordable housing shortages as the demand for legal marijuana products continues to increase in Denver and other areas of Colorado (Yakowicz, 2021).

Finally, chapter 4 examines the views of the Marquis de Condorcet on population growth. Specifically, several implicit assumptions in his work *Esquisse d'un Tableau Historique des Progress de L'Esprit Humain*. Further, we look at the Malthusian model of population growth and its principles. This is done to determine how the model results might change if the views of Condorcet were incorporated. We then consider possible reasons why Thomas Robert Malthus's essay seemingly disagrees with the opinions of Condorcet on population growth. Finally, we examine empirical analysis and historical scholarly research to determine if history has favored the views of Condorcet or Malthus on population. To our knowledge, only one paper has come close to investigating what we do here. However, Winch (1996) does not look at the implications for the Malthusian population model of Malthus' rebuke of the Condorcetian population theory. Instead, it examines general theoretical differences between Malthus and Condorcet and presents reasons for their respective viewpoints. Thus, our research breaks new ground in its examination of Malthus's famous population essay and Condorcet as a prognosticator of our modern world.

All the above chapters represent different aspects of my research interests as a regional and public economist. Specifically, my primary research concerns housing, population, and the history of the human economic journey. With my dissertation, I wish to demonstrate an ability to operate and excel in diverse fields of inquiry. This is what the inclusion of my 4th chapter adds to my dissertation: a demonstration of my versatility as a researcher. Chapter 4 considers both historical and theoretical views of population growth patterns. At the heart of such matters is the availability of means of maintenance for oneself and offspring. But the accessibility and condition of housing are critical to the preservation of the family. Thus, this interplay between population and housing is at the heart of my research interests.

CHAPTER 2-HIGH MINDED AND HIGH PRICED: LEGALIZED MARIJUANA'S IMPACT ON DENVER COLORADO HOUSING PRICES

Introduction

On November 6, 2012, Colorado voters passed Amendment 64. It legalized the private possession and use of recreational marijuana by individuals at least 21 years of age (Conklin, et al., 2020). However, such legalization was only on the state level. This has led to issues for legal marijuana dispensaries and growers in Colorado. The relevant matter for us is that marijuana remains federally illegal. Thus, federal law prohibits banks and credit unions from accepting financial transactions related to marijuana (Hudak, 2020) (Thomas & Tian, 2021) (Seefried, 2016). "With the legalization of marijuana in Colorado, an industry was born into a situation of legal conflict between state and federal law, which left the industry without banking privileges" (Seefried, 2016, p. 7). But, given the size of the legal cannabis market, banking access issues for dispensaries have ripple effects through local economies. In 2020 legal marijuana sales totaled a staggering $17.5 billion. This represented a 46% increase in revenue over the previous year. Further, most of the growth has come from "mature markets like Colorado, which grew sales by 26% to reach $2.2 billion" (Yakowicz, 2021). The industry is projected to expand at a roughly 17% Compound Annual Growth Rate (CAGR). In addition, the total annual cannabis market size is anticipated to be $47 billion by 2028 (Corbett, 2018). Such rising revenue is being driven by increased demand. Consider that "In Colorado, where market penetration is greatest in the country, 48% of Coloradans imbibe [marijuana]." Thus, Colorado's marijuana market is nearing 60%, which is alcohol's market penetration (Yakowicz, 2021).

Yet, such substantial revenue is not bankable (Hudak, 2020). Still, many legal cannabis businesses have tried to keep bank accounts. However, they are plagued with issues from an inability to process credit card payments, hold checking accounts, or take out loans. Thus, the use of financial institutions is all but untenable for dispensaries. Further, even though the Obama administration indicated that it would look the other way when banks served cannabis clients, financial institutions were still generally unwilling to do so (Quinton, 2016) (Stinson, 2015) (Berke, 2016) (Pippett, 2016). The prospect of lawful banking for legal marijuana dispensaries was made bleaker when the Trump administration reversed course and took a hard stance against the legalization of banking for marijuana businesses (Conti-Brown, 2018). Yet, some hoped that the Biden administration would prove more friendly towards dispensary banking access policies. However, such support has not materialized (Sheehey, 2021). For example, consider the Secure and Fair Enforcement (SAFE) banking act stalled in the Senate (117th Congress, 2022). Should such legislation pass, it would remove many hurdles dispensaries face when seeking banking services (Seefried, 2019a) (Seefried, 2016). Little wonder roughly 40% of Colorado marijuana businesses never even attempt professional use of a bank. The above impediments mean that "cannabis entrepreneurs meet all their obligations with cash" (Seefried, 2019b, p. 167). But all this currency floating around has led to crime against legalized marijuana dispensaries (Quinton, 2016) (Seefried, 2016). Thus, dispensaries face a quandary regarding the lack of banking access and the crime-inducing personal storage of wealth.

Given the above, we propose dispensaries may well invest their disposable funds in Colorado's real estate market. Such investment would increase demand and thus home values. Such a belief was motivated by reports of increased numbers of cash property purchases from Colorado realtors. They speculated that legalized marijuana and its dispensaries could be at least partially responsible for the trend. Sundie Seefried, the former CEO of Partners Colorado Credit Union, considered such suspicions possible. Partners are the only known financial institution to openly work with dispensaries (Seefried, 2016) (Seefried, 2019a) (Seefried, 2019b). Furthermore, such a hypothesis was supported by the Rocky Mountain Drug Task Force, whose duty is to monitor violations of marijuana-related laws (Snowden, 2020). More importantly, research has shown that illegal drug money was responsible for a boom in cash purchases of homes in Miami, Florida. Between the 1970s and 80s, it was found that as many as 1 in 5 Miami homes sold were associated with non-bankable cocaine money (Navarro, 2013). Additionally, "econometric models…show that fluctuations in single-family home prices in major urban areas in Colombia were closely related to cocaine production" (Navarro, 2013, p. 71). Further, it has been proposed that an association exists between opium exports and increased home prices in Kabul, Afghanistan (Melik, 2009). Thus, our hypothesis has precedent.

Interestingly, recent studies seem to support a hypothesis of dispensaries investing in real estate. Researchers find that the legalization of cannabis results in a roughly 6-8% increase in Colorado home values for affected areas. Further, the apparent cause of the increased home values was an increase in demand for housing. (Cheng, et al., 2018) (Burkhardt & Flyr, 2019). Additionally, the investigation of Conklin, et al. (2020) find a positive relationship between the legalization of marijuana and home prices but is "agnostic as to the underlying cause of our results." However, Cheng, et al. (2018) are more willing to hazard an explanation of their findings.

They posit that perhaps “investors…buy more properties, for either resale or rental purpose, in populous areas in order to obtain higher expected returns” (Cheng, et al., 2018, p. 17).

Thus, we wish to continue the work begun by Cheng, et al. (2018) and determine if the authors' above statement could be correct. Specifically, we will investigate the possibility that the amount of marijuana revenue sold in Denver County is associated with increased home values. Such a finding would support our hypothesis of dispensaries investing large portions of their cash in the local housing market. We employ multiple hedonic specifications to determine any potential home price impacts of the amount of marijuana revenue generated in Denver County.

Note that it would have been ideal to cross-reference the names of home purchasers against those of dispensary owners. However, this was untenable for several reasons. First, the Denver County Assessors refused to disclose their homeowner records to us (Erffmeyer, 2021). Second, even if they had shared such data, it would have been of anecdotal use at best. This is because there would be no guarantee that a dispensary owner would purchase real estate in their name. Those purchasing homes with illegal drug money will often “use a third party to…buy real estate” and thus avoid detection (Navarro, 2013, p. 63). This is because when real estate is used to launder money, the name of the source of wealth should never be used (Navarro, 2013). One example of how to purchase a home without listing an owner’s name is the use of an LLC. When buying a home with an LLC, its name is what is recorded (Lerner, 2022). Other approaches might include the purchase of properties by those not directly related to dispensary owners. Such individuals are known as “Straw buyers,” and they are common in real estate “fraud-for-profit schemes” (Fannie Mae, 2018). For the above reasons, we must limit ourselves to the aforementioned hedonic analysis concerning a potential association between marijuana revenue and home prices.

To the best of our knowledge, our research is the first investigation of a possible mechanism by which the legalization of marijuana might be influencing Colorado home prices. Additionally, we utilize a novel dataset of Denver County home sales. Such data is superior in detail to that used by previous research. Furthermore, our investigation appears to be the first considering possible implications arising from the juxtaposition of State vs. federal legalization of marijuana. Such considerations and repercussions appear absent from existing literature and could be of value to policymakers.

We have organized the remainder of our paper as follows. We begin with a look at the historical background of marijuana in America and review the literature on marijuana and home prices in Colorado. A particular emphasis is given to research regarding Denver, Colorado. Next, we take up a discussion of our hedonic methodology and data sources. We then turn to a presentation and examination of our results. The conclusion sees us summarize and consider the possible implications of our findings.

History of Cannabis and Literature Review

Cannabis in America

Since the colonies' founding, hemp and marijuana have been woven into the very fabric of America. Hemp is one of the strongest natural fibers, thus lending itself to the manufacture of rope, sailcloth, etc. In 1619, every farmer in Virginia was required to grow hemp (Hudak, 2020). Hemp was so valuable that during the 17th to 19th centuries, it was used as legal tender for debts in Pennsylvania, Maryland, and Virginia (WGBH Educational Foundation, 1998) (Hudak, 2020). The U.S. was not the first nation to avail itself of the uses of hemp. There is evidence that China has been using hemp for the above purposes exceeding 5000 years. Of course, what would later come to be the cannabis plant's most defining feature was the intoxicating properties of its processed flowers. Given the long-recorded uses of hemp, it is little wonder that marijuana is one of man's oldest known intoxicants (Swenson, 2015). However, there is little evidence that it was widely used by early Americans for its heady properties. Save perhaps a colorful discussion by 2nd President John Adams of "hemp's mind-altering capabilities" (Hudak, 2020, p. 94).

Yet, after the Mexican revolution of 1910, Mexican immigrant workers "flooded into the U.S., introducing to American culture the recreational use of marijuana. The drug became associated with the immigrants, and the fear and prejudice about the Spanish-speaking newcomers became associated with marijuana." (WGBH Educational Foundation, 1998) (Hudak, 2020). Thus, it was not surprising to U.S. citizens when "California passed the first marijuana prohibition law aimed at recreational use in 1913" (Leung & Dutra, 2021, p. 3). Further, when the Great Depression and its "massive unemployment" arrived, it fostered more resentment towards Mexican immigrant workers and their occasional pastime of smoking marijuana. Such views found justification in the research of the day which "linked the use of marijuana with violence, crime, and other socially deviant behaviors, primarily committed by "racially inferior" or underclass communities" (WGBH Educational Foundation, 1998) (Swenson,

2015) (Helmer & Veitorisz, 1974). Thus, by 1936 all states had outlawed marijuana. The nation followed suit, and in 1937 the Federal Marijuana Tax Act was passed, which "effectively criminalized marijuana" (WGBH Educational Foundation, 1998) (Helmer & Veitorisz, 1974).

It would take roughly forty years to change the national stance on marijuana. Starting in the 1970s, eleven states decriminalized marijuana. Ironically, California would be the one to open the floodgates of legalization by permitting the use and sale of medicinal marijuana in 1996. Since then, states have continued to legalize the use of marijuana, a process that continues up to the last national election (Dezenski, 2020). In fact, after the 2020 election, 33 states have legalized medical marijuana. Additionally, 18 states and the District of Columbia fully legalized marijuana (Garber-Paul & Bort, 2021) (Leung & Dutra, 2021). This has created a unique situation for many states whereby marijuana use is legal at state levels while still being federally illegal (Leung & Dutra, 2021) (Thomas & Tian, 2021).

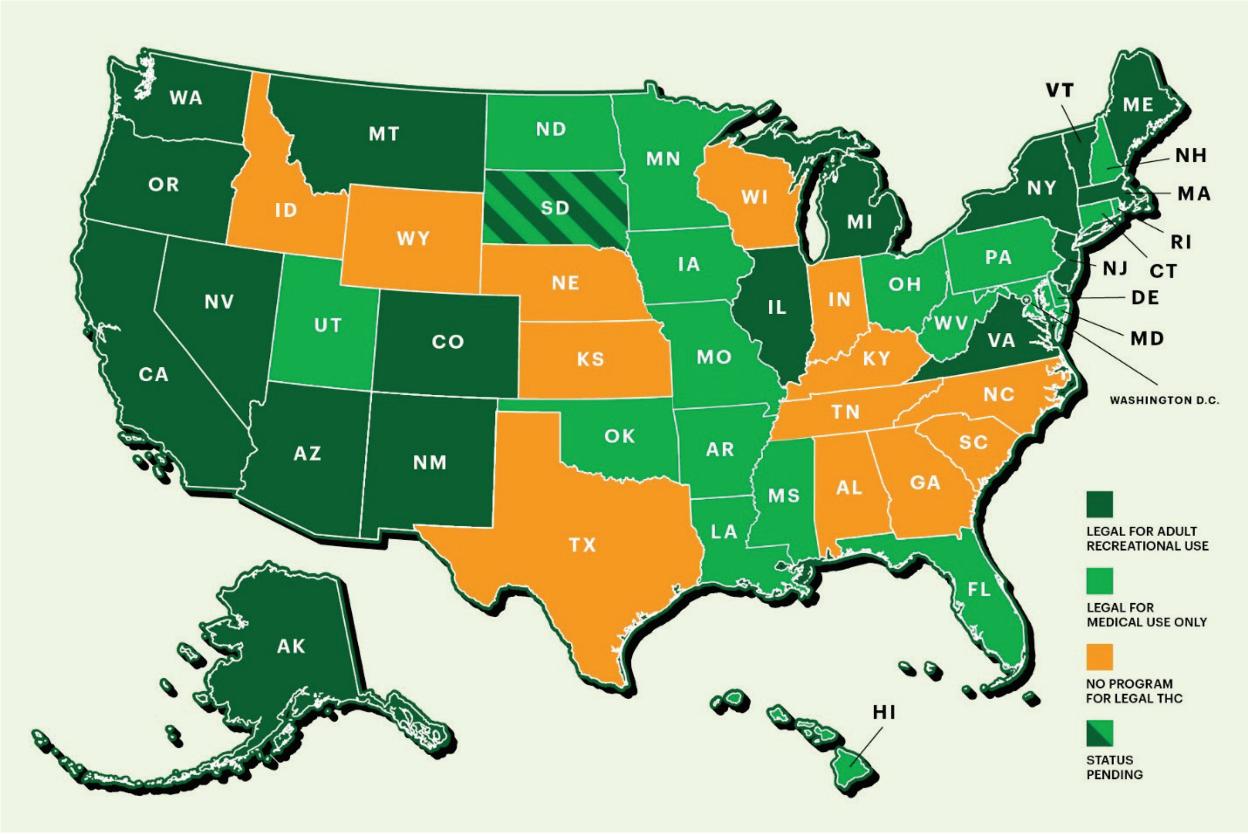

Figure 1. Legal Status of Marijuana by State (Garber-Paul & Bort, 2021)

Cannabis Research

Unsurprisingly, there has been a great deal of modern research regarding marijuana. Also, like the research from the early twentieth century, it has primarily focused on public health issues surrounding marijuana. For example, Budney, et al. (2015), Livingston, et al. (2017), Ghosh, et al. (2015), Salomonsen-Sautel, et al. (2012), Wang, et al. (2016) and Couper & Peterson (2014) or Leung & Dutra (2021), to name but a few. All said research deals with various health or public health issues surrounding the use of marijuana. The concerns range from the health impacts of increasing "Vaping cannabis" trends to "The Prevalence of Marijuana in Suspected Impaired Driving Cases in Washington State" (Budney, et al., 2015) (Couper & Peterson, 2014). The above investigations are only the proverbial tip of the iceberg regarding such inquiries.

Yet, when it comes to investigating marijuana and homes, the literature grows sparse (Conklin, et al., 2020). To our knowledge, only six papers consider such a relationship. Thus, our research contributes to a field of study which is lightly probed. However, the existing literature on the topic is insightful and utilizes well-established methodologies (Adda, et al., 2014) (Cheng, et al., 2018) (Conklin, et al., 2020) (Burkhardt & Flyr, 2019) (Tyndall, 2021) (Thomas & Tian, 2021).

The first paper considering the possible impacts of marijuana policies on home prices is the work of Adda, et al. (2014). They investigated the effect of "depenalized possession of small quantities of cannabis in the London borough of Lambeth." It is important to note that "depenalized," marijuana possession was still considered an offense. The primary focus of the research was the implications of such a policy on crime. They determined that only one type of crime increased: cannabis possession offenses. This makes sense, given the nature of the depenalization. However, "overall," there was a "fall in crime attributable to the policy." The authors went on to conduct an inquiry into the "total welfare" impacts of the policy on "local residents…as measured by house prices" (Adda, et al., 2014, p. 1130). In this regard, they used a difference-in-difference model. They found that homes in Lambeth, where cannabis possession offenses increased, saw a 13.5% decrease in home values. The other areas of Lambeth had similar home price trends to the rest of London. Thus, home prices decreased in association with rising drug possession crime in the neighborhood (Adda, et al., 2014).

The above trend of marijuana being associated with increased crime and, thus lowering housing prices is not unique. Thomas and Tian (2021) employ a "difference-in-differences, triple difference, and instrumental variables models", and determine that Washington "home prices within a 0.36-mile area around a new dispensary fall by 3–4% on average, relative to control areas" (Thomas & Tian, 2021, p. 1) They continue by investigating if dispensaries increase crime in the area, as crime can negatively impact local home values. Thomas and Tian (2021) fail to uncover any significant increase in local property values or violent crime in areas with dispensaries. What they do find is an increase in "nuisance" crimes, which are defined as "loitering, disturbing the peace, or traffic crimes." They also discover a highly significant decrease in drug-related crimes. Thomas and Tian's (2021) work fits very closely with that of Adda, et al. (2014) above (Thomas & Tian, 2021, p. 13). Both papers discover an increase in non-violent, non-property crimes associated with either dispensary opening or depenalization, respectively. Further, Adda, et al. (2014) shows it is increasing crime, which is depressing home prices. Also, Thomas & Tian's (2021) 3-4% decrease in home value is consistent with research on the impact of local crime on home values (Linden & Rockoff, 2008).

A third paper investigates why marijuana-related crime seems to be lowering home prices. In Tyndall (2021), the author examines the impact of dispensaries on surrounding home prices in Vancouver, British Columbia. Once again, a difference-in-difference approach is the primary means of investigation. Tyndall (2021) finds "no evidence that marijuana dispensaries increase local home values" (Tyndall, 2021, p. 1093). Interestingly, it appears that the presence of a dispensary lowers home values within a 100-meter radius by 3.7%. This negative effect dies out further than 100 meters from a dispensary. It is important to note that Tyndall (2021) looked at largely illegal dispensaries. Thus, the presence of a dispensary was equivalent to the presence of crime near the homes being sold. But consider the difference-in-difference analysis of Linden & Rockoff (2008). They found that home values within a 0.1-mile (161-meter) radius of a known crime risk saw a roughly 4% decrease in home values. However, homes beyond a 0.1-mile radius experienced no such reduction in value. Tyndall (2021) attributes the decreased home values to the presence of a dispensary. However, the results are almost identical to the impact of criminal entities near selling homes. The results of Tyndall (2021) are also in keeping with the above-mentioned Adda, et al. (2014) and Thomas & Tian (2021). In both those cases, home values decreased as marijuana policies caused an increase in local crime. In short, Tyndall (2021) is almost certainly seeing a decrease in home values, owing to the illegal status of the dispensary and the crime it entails. This is not a concern Tyndall (2021) addresses empirically.

Thus far, the literature on marijuana and housing has painted a picture of dispensaries increasing petty crime and thus decreasing housing prices in the neighborhood. However, when marijuana is legalized, the above trend seems to reverse (Burkhardt & Flyr, 2019) (Brinkman & Mok-Lamme, 2019) (Burkhardt & Goemans, 2019) (Cheng, et al., 2018) (Conklin, et al., 2020). Recall that for Adda, et al. (2014) and Tyndall (2021), marijuana was illegal. Only in Thomas & Tian (2021) was marijuana legal and still associated with increased "nuisance" crime. But Washington is unique in terms of the laws surrounding its marijuana legality. Firstly, it is one of the only states to prohibit the vertical integration of dispensaries. Thus, a dispensary cannot grow or cultivate the plants used in its final products. Instead, it must purchase such goods from a separate cultivator (Leynseele, 2021). Secondly, Washington has some of the nation's strictest "seed to sale" laws (Jenkins, 2014). In short, Washington is not representative of states that have legalized marijuana. For a more detailed discussion of the unique legal features of Washington, see Rasmussen (2022).

Now let us consider what the literature says regarding legalized marijuana and home prices. When one speaks of the legalization of marijuana, one talks of Colorado. This is because perhaps no state is more representative of the trend of state legalization than the first one to do so (Cheng, et al., 2018). Likewise, recall from our introduction that Colorado has become one of the most significant growth drivers in the legal marijuana industry (Yakowicz, 2021). Yet, unlike Washington, Colorado allows vertical integration of marijuana dispensaries and voluntary recreational seed-to-sale reporting (Leynseele, 2021) (Stanojevic, 2020). This supports the appropriateness of state-level analysis.

We begin with the crime research of Burkhardt & Goemans (2019). Employing a difference-in-difference approach for Denver, Colorado, they discover that the presence of a dispensary reduces violent crimes in above-median-income neighborhoods. Dispensary presence is also associated with a decrease in non-marijuana-related drug crimes. Only one type of crime increased: nearby vehicle break-ins (Burkhardt & Goemans, 2019). But the fact that violent crimes decrease when a dispensary is located in an above-median-income neighborhood is more impactful than it might initially seem. Boggess, et al. (2014) found that contrary to expectations, dispensaries were not located in poor areas (Boggess, et al., 2014).

Brinkman & Mok-Lamme (2019) also investigate the impact of dispensaries on crime in Denver, Colorado. They employ a first-difference methodology and find that supplementing an additional dispensary in a neighborhood results in about a “19 percent decline” in local crime rates (Brinkman & Mok-Lamme, 2019, p. 1). Such findings are very much in keeping with national research by Huber, et al. (2016). They observed approximately a 4-12% decrease in nationwide robberies, larcenies, and burglaries “due to the legalization of medicinal marijuana” (Huber, et al., 2016, p. 1). So, we see that the legalization of marijuana and its dispensaries appear to lower overall crime in Colorado.

Now we turn to a consideration of the apparent effect of the legalization of marijuana on Colorado home prices. The first paper investigating a possible correlation between housing prices and the legalization of marijuana is the work of Conklin, et al. (2020). Here the authors also use a difference-in-difference approach and data from the City of Denver, Colorado. They determine that post-recreational marijuana legalization, areas within 0.1-miles of a dispensary saw an 8.4% increase in home values “relative to houses that are located… (between 0.1 miles and 0.25 miles)” away (Conklin, et al., 2020, p. 1). The authors note that Colorado is an ideal state to use for the investigation of the effects of dispensaries on “nearby house prices…because only existing medical marijuana facilities were allowed to sell recreational marijuana, which facilitates identification of the incremental effects of recreational marijuana.” Conklin, et al. (2020) finish saying that one possible explanation of their observed results could be an “increase in housing demand” that is increasing prices near dispensaries (Conklin, et al., 2020, p. 26).

The above findings are reiterated by Burkhardt & Flyr (2019). They use a difference-in-difference approach to determine “the effect of dispensary openings by comparing sales prices before and after the introduction of a new dispensary in treated areas relative to control areas, controlling for the presence of existing dispensaries” (Burkhardt & Flyr, 2019, p. 1). They “find that the introduction of a dispensary increases home transaction prices by 7.7% for houses within 0.25 miles of a new dispensary relative to control houses on average, but this impact diminishes to around 4.7% for houses within 0.25–0.5 miles of a new dispensary” (Burkhardt & Flyr, 2019, p. 2) The data used is on dispensaries, housing characteristics, and sale prices from the City of Denver. The work of Burkhardt & Flyr (2019) reinforces the findings of Conklin, et al. (2020), as both papers find similar magnitudes for the effects of dispensaries on local home prices. The fact that Burkhardt & Flyr's (2019) results are for new dispensaries implies that the findings of Conklin, et al. (2020) “are not simply due to the passing of the recreational law” (Burkhardt & Flyr, 2019, p. 3). That is, the work of Conklin, et al. (2020) and Burkhardt & Flyr (2019) together strongly indicate that it is the dispensaries themselves that are responsible for the increase in housing prices, and not neighborhood characteristics, like crime levels (Burkhardt & Flyr, 2019) (Conklin, et al., 2020). This supports our notion that dispensaries might increase home prices via real estate investment. Recall that both Conklin, et al. (2020) and Burkhardt & Flyr (2019) find local home prices to increase by 8.4% and 7.7%, respectively. Hence, Burkhardt & Flyr (2019) see this as "compelling evidence that marijuana dispensaries have relatively large effects on neighboring housing prices…," compared to the introduction of other new neighborhood structures (Burkhardt & Flyr, 2019, p. 4). One hypothesis explored here is that these patterns may interrelate investment in local real estate.

Finally, consider the work of Cheng, et al. (2018). The authors employ a difference-in-difference analysis of time series and cross-sectional data to determine that the legalization of recreational marijuana in Colorado correlates with a 6% increase in housing values. Further, the authors find that the main driver of such an increase is a rise in demand for low to middle-value housing properties in urban and metropolitan areas. Additionally, Cheng, et al. (2018) provide the following possible explanation for the observed increase in urban housing demand: it might result from the fact that "investors could buy more properties, for either resale or rental purpose, in populous areas in order to obtain higher expected returns" (Cheng, et al., 2018, p. 1601). Finally, the authors note that the chance of a property selling in urban areas increased post-legalization by 21 percentage points (Cheng, et al., 2018).

Existing literature paints a consistent picture of the impacts of marijuana legalization in Colorado. Such policies and their resultant dispensaries are unanimously found to increase home values and result in an overall decrease in surrounding crime rates (Conklin, et al., 2020) (Burkhardt & Goemans, 2019) (Burkhardt & Flyr, 2019) (Brinkman & Mok-Lamme, 2019). Taken together, the work of Cheng, et al. (2018), Conklin, et al. (2020), and Burkhardt & Flyr (2019) "suggests that dispensary conversions, dispensary openings, and legalization status have similar effects on housing prices" (Burkhardt & Flyr, 2019, p. 4).

Hence, existing literature paints a consistent picture of marijuana legalization positively impacting Colorado home prices. Yet such a tableau lacks a decisive process by which such an association would exist. It is into this void that we step with our hypothesis that dispensaries might represent Cheng, et al. (2018) 's investors, who are thought to be responsible for the witnessed increase in housing values. To our knowledge, we are the first to investigate such a proposed mechanism. Further, we are unaware of any research that has addressed the possible implications of differing state and federal legal statuses of marijuana. Thus, our research is unique and shines new light on specific impacts of the trend of states' legalization of a federally illegal substance.

Implications of Existing Literature

Now consider what the above research means for our investigation. First, let us recall that Conklin, et al. (2020) found home values within a 0.1-mile radius of a dispensary to be increasing in value after the legalization of recreational marijuana. Further, Burkhardt & Flyr (2019) discovered similar results for the opening of new dispensaries. But by the logic of Linden & Rockoff (2008), it must be that the risk of crime near a dispensary is low. Otherwise, we should see a decrease in home prices within the 0.1-mile radius. Such a conclusion aligns with the above research on crime and marijuana legalization. Remember that such investigation determined that the legalization of marijuana does not appear to be correlated with an increase in Colorado crime (Burkhardt & Goemans, 2019). Instead, legalization seems to decrease overall crime (Brinkman & Mok-Lamme, 2019). Brinkman & Mok-Lamme (2019) offer one possible solution for the witnessed decrease in crime: it might result from altered post-legalization policing habits around dispensaries. Yet, this does not fit with the empirical fact that immediately following the recreational legalization of marijuana, "the Denver Police Department…logged over 200 burglaries at marijuana businesses, as well as shoplifting and other crimes" (Quinton, 2016).

Another explanation for the decrease in crime associated with Colorado dispensaries is that dispensaries responded to the initial criminality by moving cash offsite. Thus crime would be disincentivized. Yet, they cannot legally bank the money (Seefried, 2016) (Thomas & Tian, 2021) (Pippett, 2016). Further, holding the cash in offsite safes might make targets of the owners and expose their money to inflationary losses.

While safe deposit boxes might seem like a natural solution, they are ill-suited to dispensaries' needs. Most importantly, safe deposit boxes can be seized by the government. This happened when "Armed with a warrant, agents with the FBI and Drug Enforcement Administration pulled each of…several hundred [safe deposit]boxes out of the walls and seized all the contents." The raid occurred because the federal government harbored suspicion of "ill-gotten wealth" being housed in the safe deposit boxes (Finnegan, 2021). As recreational marijuana is federally illegal, this presents a real danger for any dispensary owner tempted to store their wealth in a safe deposit box (Hudak, 2020).

Further, as many banks close brick-and-mortar locations, they often drill and seize the contents of safe deposit boxes (Cowley, 2019). In addition to the threat of seizure, many banks "expressly forbid storing cash in a safe deposit box" (Niedt, 2022). More importantly, safe deposit boxes are not insured. Thus, the contents are at the mercy of fire, flood, and theft. All the above creates a situation where hundreds of thousands to millions of dollars go missing from safe deposit boxes every year. In fact, "around 33,000 [safe deposit] boxes a year are harmed by accidents, natural disasters and thefts." Interestingly, one of the primary sources of loss are the banks themselves. As the contents are not documented and lack insurance, there is often no record of what has been taken. Further, customers are rarely able to recover their losses (Cowley, 2019). This would be doubly true of marijuana money. On top of the risk of seizure or loss, cash put in a safe deposit box will lose value over time (Niedt, 2022). Given all the above, keeping money in safe deposit boxes is highly discouraged, especially for businesses (Seidel, 2019).

Cryptocurrency would seem to offer another avenue for dispensary owners to store their wealth. However, Green Wave Advisors Banking on Cannabis report had this advice for marijuana businesses contemplating cryptocurrencies: "We are cautious on the use of Cryptocurrencies as a viable banking solution" (Green Wave Advisors LLC, 2017, p. 4). They go on to say that "Because cryptocurrencies are so controversial (for many reasons), we believe its use raises added concern for the cannabis industry, which already faces its own unique challenges for banking and do not consider it a viable option at this point in time" (Green Wave Advisors LLC, 2017, p. 8). Apart from Green Wave's legal concerns, there is the matter of stability. Consider that "The price of Bitcoin — and all cryptocurrency, for that matter — is incredibly volatile because it is such a young currency and market. It is common for the price of Bitcoin to experience wild swings within a day or even minutes. This makes trading a dangerous venture" (Khojikian, 2021). So, while cryptocurrencies might avoid some of the dangers of seizure that safe deposit boxes suffer from, it is a perilous place for dispensary owners to put their wealth.

Yet, by purchasing local real estate, dispensary owners will have put their money into an investment that simultaneously protects their wealth from crime, seizure, and inflation (Schaub, 2016) (Pippett, 2016) (Imel & Ruedebusch, 2017). Additionally, home value appreciation is stable and generally outperforms other assets over the long run (Schaub, 2016). Another reason that real estate might represent a sound place for dispensaries to store wealth is its ability to launder money. A home can be purchased entirely in cash, regardless of the source of that wealth. Then the owner can quickly resell the property and take that money to the bank, no questions asked (Seefried, 2019a). The use of real estate to launder money in this way is well documented. Consider that during the " late 1970s and mid-1980s…more than one in five real estate transactions in Miami during this period were done with hard cash" for "cocaine money laundering" purposes (Navarro, 2013, p. 64). This is possible because purchasing a home with cash is faster and more efficient than a home loan (Henricks, 2022).

Furthermore, "Buyers who have cash in hand are very attractive to sellers, as it streamlines the whole process" (Ellis, 2020). Most importantly, buying a home with cash requires no bank account for dispensaries. Dispensaries can pay with cash, a money order, or a wire transfer. For instance, purchasing a home via money order requires only a trip to the local post office or any business offering money order services (Gleeson, 2019). Similarly, for wire transfers, bank accounts are not required. This is largely due to the proliferation of online money-wiring services like Venmo (Zak, 2021). While "Buying a house with cash may seem far-fetched…it…occurs relatively frequently. As a matter of fact, about one-fifth of buyers pay for their homes with cash." Interestingly, "One of the most significant sources of cash home buyers are companies that invest in real estate" (Childs, 2022). Homes and money laundering are discussed in more detail in Rasmussen (2022).

But, if local dispensaries reacted to an initial increase in crime via the acquisition of local real estate, it would increase demand for homes in urban areas. But, recall this was precisely what Cheng, et al. (2018) found to be occurring. Hence, as demand increases, it could lead to a rise in home prices. In line with such thinking, most Colorado dispensaries are in the major urban areas of Denver, Boulder, Fort Collins, and Pueblo (Kush Tourism, 2018). Additionally, it is generally held real estate investment dogma that return on investment (ROI) will be higher if real estate investors participate in local metropolitan areas (Schaub, 2016) (Kiyosaki, 2016). Further, recall that Conklin, et al. (2020) "hypothesize" an "increase in housing demand " as a likely reason for their observed increase in housing values surrounding dispensaries. Additionally, recall Cheng, et al. (2018) speculated on a possible explanation for the post-legalization rise in urban and metropolitan demand for housing: "investors could buy more properties, for either resale or rental purpose, in populous areas in order to obtain higher expected returns" (Cheng, et al., 2018, p. 1601). But this implies dispensaries have strong incentives to invest in local real estate. That is, in Denver County.

Overall, the above research points towards a need to investigate a real possibility: marijuana dispensaries investing in local real estate, thus driving up home prices in urban/metropolitan areas of Colorado. Recall that both Cheng, et al. (2018) and Conklin, et al. (2020) propose that their results could stem from increased housing demand. Yet so far, no research has looked at the why of rising home prices. Further, Burkhardt & Flyr (2019) indicate that the above question would benefit from hedonic analysis (Burkhardt & Flyr, 2019, pp. 2-3). Thus, we will investigate our hypothesized mechanism using a Rosen (1974)-style hedonic model. Our investigation aims to determine if a statistically significant positive relationship exists between the amount of marijuana revenue generated and home prices in Denver County. Such a result would be evidence in favor of our hypothesized mechanism of home value increases. Note that Navarro (2013) observed an increase in demand for homes in "Columbian and Bolivian cities" associated with the laundering of cocaine money. In that case, there was a "positive and statistically significant" relationship between "cocaine exports" and "home prices" (Navarro, 2013, p. 69). Thus our hypothesis has precedent.

Methodology

Primary Methods

One might consider three primary models for analyzing home prices; hedonic, repeat sales, and the "hybrid" model. Of these, we select the hedonic method and will thus begin by detailing its background and reasons for selection. We then briefly consider the other two model choices and their lack of suitability for our work. We conclude this section by discussing our specific application of hedonic methodology.

Hedonic models have long been a standard tool of economic inquiry. They date back as far as Court (1939) and perhaps even Haas (1922) (Haan & Diewert, 2013). However, Lancaster (1966) was the first to truly lay the groundwork for hedonic theory (Sopranzetti, 2015). According to his hypothesis, the utility of a good is nothing but the sum of the utility offered by the individual "characteristics" it possesses (Lancaster, 1966, p. 154). For instance, a home's utility can be considered the sum of the utility that arises from each characteristic it possesses. That is, from the number of bathrooms and its ability to serve as an investment, or launder cash (Navarro, 2013) (Diewert, 2013) (Cheng, et al., 2018). However, it would be Rosen (1974) who would first apply the above hedonic theory to pricing (Sopranzetti, 2015) (Oust, et al., 2020). Rosen (1974) held that a good's price is nothing but the sum of the value of each of the characteristics comprising the good. Thus, a good's price p can be thought of as the dependent variable to be regressed on the independent variables $z = (z_1, z_2, \dots, z_n)$ representing that good's characteristics (Rosen, 1974).

Since their inception, hedonic models have been employed to investigate such diverse goods as automobiles, farmland, or the value of clean air. However, hedonic models have become the bread-and-butter methodology for econometric real estate analysis. This is because of their ability to "deconstruct the price of an asset into the asset's component parts, and then use some form of ordinary least squares regression analysis to examine how each individual piece uniquely contributes to the item's overall value." (Sopranzetti, 2015, pp. 2,19) (Haan & Diewert, 2013, p. 50). Additionally, "it has been widely recognized that it is appropriate to control statistically for the varying characteristics of properties in inferring price" of homes (Case & Quigley, 1991, p. 50). But the above is what our hypothesis demands, the ability to determine any potential impact that marijuana revenue sales characteristics have on Denver County home prices.

Yet, despite having many advantages for real estate analysis, hedonic home price models suffer from several potential issues. The first challenge is that we must compare homes that are as homogenous as possible in their characteristics. But "each property has a unique location and usually a unique set of structural characteristics, this makes comparing homes sold more difficult," as "dwellings are heterogeneous." No two dwellings are identical, if only because they cannot occupy quite the same location" (Diewert, 2013, p. 22) (Wood, 2005) (Oust, et al., 2020, p. 196) (Case, et al., 1991). Existing hedonic housing literature consistently attempts to minimize the above heterogeneity issue by including as many price-determining property characteristics as possible. The most important of these characteristics often being some form of the following; "the area of the structure (in squared feet or in meters squared); the area of the land that the structure sits on (in squared feet or meters squared); the location of the property; the age of the structure; the type of structure (condo, single-family home, etc.); the materials used in the construction of the house, and other price determining characteristics such as the number of bedrooms, the number of bathrooms, a garage, a swimming pool, air conditioning, distance to amenities, etc." (Diewert, 2013, p. 25) (Meese & Wallace, 1991, p. 320) (Shiller & Case, 1987, p. 5) (Oust, et al., 2020, p. 184) (Bailey, et al., 1963, p. 934) (Greenlees, 1982, pp. 6-7) (Case & Quigley, 1991, pp. 50,54) (Case, et al., 1991, pp. 288,294).

Fortunately, our dataset is comprehensive and contains information on all of the above characteristics, save swimming pool presence. In fact, we employ characteristics in addition to those listed above. But most importantly, we can utilize neighborhood fixed effects. Thus, we can account for the differences in the location of homes sold. The ability to locate a home at the neighborhood level has been shown to improve the accuracy of hedonic models by roughly 34% (Oust, et al., 2020). Additionally, both Conklin, et al. (2020) and Burkhardt & Flyr (2019) employed neighborhood fixed effects in their investigation of the impact of dispensaries on home prices. We also utilize controls for the primary type of material used in home construction. Further, we apply characteristics such as the number of fireplaces and the area of any garage present. The only above-listed characteristic we do not have information on is the presence of a swimming pool. This is because Denver County taxes homes based on the presence of a swimming pool. Thus, most owners fill in any pools to avoid taxation. Additionally, pools are costly to maintain in a state with such pronounced winters. For these reasons, Denver County Assessors do not keep records on the presence of swimming pools (Erffmeyer, 2021). Finally, one characteristic controlled by default is the school district. A vast body of literature indicates an association between school quality and home prices (Weimer & Wolkoff, 2001). However, as Denver County has only one school district, we do not need to control for it (Farrell & Layman, 2019). Given all the above, we feel confident in our ability to robustly account for the heterogeneity of home location (Diewert, 2013).

The second obstacle to surmount with hedonic models is that "transactions are sporadic." Yet, between sales, the home suffers age-related depreciation and can benefit from renovation-based increases in value (Diewert, 2013, p. 22) (Shiller & Case, 1987, p. 7). An obvious way to overcome depreciation and renovation effects on home prices is to include age and renovation records in your hedonic analysis. However, county assessors rarely seem to document renovation data (Erffmeyer, 2021) (Beavers, 2020). Luckily our dataset contains information on both age and renovation. The possession of this data allows us to deal with two of the most significant issues of "sporadic" transactions. In the case of depreciation, you can account for it by including the year a property was built, ala Shiller & Case (1987). For instance, the property's age can account for the depreciation from wear and tear over time. It can also capture changes in consumer home preference tastes over time. In short, by having such data, we "can capture the effect of the age of the unit on its value" (Shiller & Case, 1987, p. 8). But we go further and account for both depreciation and renovation with the same data point: the effective year of home construction. The effective year of construction is the year of construction updated for renovations. Suppose a kitchen is renovated between home sales or the basement is finished. We will account for it in the effective year of construction of the property. Our Denver County Assessor data determines the effective age of a property is "an adjusted date of year built as a result owing to a remodel, renovation or large addition." Further, they "calculate an effective YOC after a significant remodel or addition…. We weight the years based on the contribution[of the home's remodel]. So, we might say an original

1930 home still has 60% of its original components and was remodeled in 2020 which would be weighted 40%. Thus, we have an effective year of construction of (1930 x 60%)+(2020 x 40%) = 1966" (Erffmeyer, 2021). The ability of the hedonics to include depreciation and renovation accounting information is a great advantage of the model (Case, et al., 1991). The above motivates our investigation and confirmation of the superiority afforded by including the year of effective construction. Such a comparison was made against the more conventional age at the time of the sale home attribute. Results of this test are in appendix vi: age at sale vs. effective year built. Additionally, we discuss our construction of the age at the time of sale characteristic in appendix i: housing data discussion. But returning to the matter at hand, our data allows us to control for the second concern of hedonic models: sporadic transactions (Diewert, 2013).

Thus far, we have only looked at the hedonic model. Yet, there are two other home price models due consideration. The first is the most significant contender of hedonics: The repeat sales method. This technique was primarily pioneered by Bailey, et al. (1963) (Shiller & Case, 1987). A repeat sales method compares "properties that have sold more than once over the sample period." By doing so, you are guaranteed that the location of the home sold is homogenous. Thus, the repeat sales method is very good at overcoming the heterogeneity of location issue discussed above (Diewert, 2013, p. 26) (Oust, et al., 2020, pp. 185,200) (Bailey, et al., 1963, p. 934). However, this technique is not suitable for our analysis. This is because the repeat sales method assumes that the sale price of a home today is equal to the sale price of the house yesterday, plus the change in the value of the constant quality home over time. Thus, the model does not allow us to analyze the possible impact of the amount of marijuana sold on home prices. Specifically, as the homes must be of constant quality, characteristics cannot change. That is, marijuana revenue must remain constant. Even if a repeat sales approach was theoretically feasible, it suffers from concerning weaknesses. The greatest is that repeatedly sold homes are but a small and usually unrepresentative subsample of all homes marketed in an area (Shiller & Case, 1987) (Case, et al., 1991) (Clap & Giaccotto, 1992). Consider that should we use only repeatedly sold homes, our sample size decreases by over two thirds.

Further, when one only considers repeatedly sold homes, one often encounters "lemons" bias, since starter homes sell more frequently as a result of people upgrading as their wealth rises" (Hill, 2013, p. 883). This is the main reason that hedonic methods are found to be more time-period accurate predictors of home values (Shimizu, et al., 2010). Thus, our results from a repeat sales approach would not be generalizable for the majority of homes sold in Denver County. Additionally, depreciation makes the constant quality assumption of repeat sales models virtually impossible to enforce (Hill, 2013). Still, with all its many shortcomings, well-known housing price indices use the repeat sales approach. Consider S&P/Case-Shiller or FHFA. These indices' popularity stems from the constant quality assumption. Such an assumption allows the repeat sales model to obtain home value estimates without the large amounts of housing characteristics data necessary for the hedonic model. That is, repeat sales methods use the fallacious constant quality assumption to sidestep large data requirements they would otherwise have to fulfill (Shiller & Case, 1987) (Diewert, 2013).

But that is just the issue with the repeat sales method: it does not allow one to break down the impact of the home's characteristics on its value (Hill, 2013). For such a task, we need a hedonic model. Further, as data availability increases, the hedonic model becomes ever better at outperforming the repeat sales technique. Thus, one should employ a hedonic approach as it can "overcome the limitations of the…repeat-sales indexes but [they] are seldom constructed because of a lack of data." Yet, we possess sufficient data for the hedonic approach to outperform a repeat sales approach (Shimizu, et al., 2010) (Dorsey, et al., 2010) (Diewert, 2013). For all the above reasons, we feel secure in our selection of the hedonic approach over that of the repeat sales method.

Another possibility would be to combine a hedonic and repeat sales approach into a "hybrid" method. This was first undertaken by Case & Quigley (1991) and Case, et al. (1991). "The rationale for hybrid methods is to try and combine the best features of each approach" (Hill, 2013, p. 897). However, the "hybrid" approach incorporates the repeat sales approach, and "The repeat-sales model implicitly assumes that repeat sales and single sales are drawn from the same population of housing sale transactions." Thus, "This assumption is also implicit in the hybrid approach" (Case, et al., 1991, p. 287). Yet, Clap & Giaccotto (1992) show this is not always the case. That is, repeatedly sold homes are generally not representative of the average home sold in an area (Clap & Giaccotto, 1992). Finally, the hybrid approach can be outperformed by a hedonic model with the quality of data we possess (Case, et al., 1991). Still, the literature is divided on hybrid models. Some find the hybrid model has a slight advantage over the hedonic (Case & Quigley, 1991). Yet others determine the hedonic model superior (Case, et al., 1991) (Hill, 2013) (Oust, et al., 2020). Thus, we conduct a robustness check of our hedonic method. We employ a partial implementation of the hybrid approach of Case, et al. (1991). We find our results robust to such a change in model specification. The findings of such work are presented in table 2.

Considering all the above, the hedonic model represents a theoretically superior choice. Further, it is a well-established approach (Haan & Diewert, 2013). Additionally, we have the data to employ such a technique properly. In the age of big data, the hedonic model is fast becoming the most accurate of the three models discussed above. As Hill (2013) notes in the conclusion of his review and comparison of hedonic, repeat sales, and hybrid models, "The hedonic approach provides a rich and flexible structure that allows index providers to tailor the method to the available data and the needs of users. Hoffman and Lorenz (2006) go further and say, "the future will belong to hedonic indices" (Hill, 2013, p. 907).

Thus, we employ a log-linear hedonic modeling approach for all the above reasons to investigate our hypothesis. Such a technique is theoretically based on Rosen (1974) and empirically implemented via de Haan & Diewert (2013). Utilization of a log-linear hedonic model is a common approach to hedonic real estate modeling. In fact, it is one of the two primary means to "estimate the marginal contributions of the[housing] characteristics" on the sale price, or natural logarithm of the sale price, of the home (Haan & Diewert, 2013, p. 50). This is because such a model is considered theoretically robust (Greenlees, 1982). Note that the log-linear model is also known as the semi-log model (Greene, 2012). The advantage of a log-log or log-linear model specification is that it allows us to see the percentage impact of each explanatory variable on home prices (Greenlees, 1982). Specifically, "One attractive feature of the log-log model, which has made it popular in applied work, is that the slope coefficient β_n measures the elasticity of *Y* with respect to *X*, that is, the percentage change in *Y* for a given (small) percentage change in *X*" (Gujarati, et al., 2009, p. 172). Suppose we estimate the slope coefficient on *X* to be 0.2. Then the above tells us that for a 1% increase in *X,* there is an associated 0.2% increase in Y. However, as we are employing a semi-log model, we will have both log-log relationships, as discussed above, and log-linear ones. When the dependent variable *Y* is logged, and the independent variable *X* is not, one should interpret the slope coefficient of *X* differently than in the log-log case. Consider again that *X* has a slope coefficient of 0.2. Thus, in a log-linear relationship, a 1 unit increase in X is associated with a 20% increase in *Y* (Stock & Watson, 2007).

Our semi-log model is presented in equation (1). It aims to determine the association between the amount of legal marijuana sold and single-family home prices in Denver County.

$$ln(y_{imy}) = \alpha + \sum_{j=1}^{J} \beta_j ln\,(QC_{jimy}) + \sum_{k=1}^{K} \delta_k QD_{kimy} + \sum_{e=1}^{E} \xi_{\ e} ExtWls_{ie} + \theta\, ln(MedRev_{(m-6)y})$$
$$+ \phi\, ln(RecRev_{(m-6)y}) + \sum_{n=1}^{N} \eta_n NBHD_{in} + \sum_{m=1}^{M} \mu_m Month_{im} + \sum_{y=1}^{Y} \psi_y Year_{iy}$$
$$+ \epsilon_{imy} \tag{1}$$

Where y_{imy} is the $\text{sale price}_{imy} - (\text{concessions and other adjustments})_{imy}$ of home *i* sold in month *m* of year *y*, QC_{jimy} is the quantity of home *i's j*th continuous characteristic observed in month *m* of year *y*, QD_{kimy} is the quantity of home *i's k*th discrete characteristic in month *m* of year *y*, $ExtWls_{ie}$ is a dummy variable assuming a value of 1 if home *i's* exterior walls are made of material *e* and 0 otherwise, $MedRev_{(m-6)y}$ is the total medicinal marijuana revenue generated in month (*m-6*) of year *y*, $RecRev_{(m-6)y}$ is the total recreational marijuana revenue generated in month (*m-6*) of year *y*, $NBHD_{in}$ is a neighborhood dummy assuming a value of 1 if home *i* sold in neighborhood *n* and 0 otherwise, $Month_{im}$ is a month dummy variable assuming a value of 1 if home *i* sold in month *m* and 0 otherwise, $Year_{iy}$ is a year dummy assuming a value of 1 if home *i* sold in year *y* and 0 otherwise, and ϵ_{imy} is the clustered, heteroscedasticity, and autocorrelation robust error term for home *i* sold in month *m* of year *y*. Finally, α is the intercept, while $\beta, \delta, \xi, \theta, \phi, \eta, \mu, \psi$ are the model coefficients to be estimated.

Now let us consider the logic behind the inclusion of the various elements of equation (1). First, we have the natural concession adjusted sale price. Note that "concessions are the costs that a seller agrees to pay on behalf of the buyer during the sale of a home, at closing. Seller's concessions can cover closing costs including but not limited to lender origination fees, discount points, title insurance costs, loan processing fees, attorney's fees, credit report pulling fees, appraisal fees, inspection fees, and transfer taxes" (Zillow, 2021a). Further, other adjustments are typically personal property the seller includes with the home, at no additional cost to the buyer (Erffmeyer, 2021). Thus, previous authors' lack of home price-lowering concessions could lead to a sale price that overestimates the home's value. But the impact of various characteristics on such overestimated home values will be inflated. (Burkhardt & Flyr, 2019) (Cheng, et al., 2018) (Conklin, et al., 2020). Additionally, we employ the natural logarithm of the concession-adjusted sale price as the dependent variable. This is in keeping with the previous literature on our topic. Such authors had dependent variables that were either the natural logarithm of the nominal sale price of the home or the nominal sale price in constant 2010 dollars (Burkhardt & Flyr, 2019) (Conklin, et al.,

2020) (Cheng, et al., 2018). Also, “In real estate modeling, it is common to use the most recent transaction price as a dependent variable” (Sopranzetti, 2015, p. 8). Thus, we have chosen to use the natural logarithm of the sale price as our dependent variable. This allows us to capture the percentage change in home *i’s* value associated with changes of the independent variables (Burkhardt & Flyr, 2019) (Cheng, et al., 2018) (Conklin, et al., 2020)

Next, we have separated discrete and continuous characteristics after the fashion of Case, et al. (1991) and Case & Quigley (1991). Standard hedonic methods permit such an approach (Haan & Diewert, 2013). So doing allows us to take the natural logarithm of continuous characteristics and thus determine what a small percentage change in any of our continuous characteristics would mean in terms of a percentage change in the home's sale price. However, when discrete characteristics assume a value of zero, it is because the characteristic is not present. Hence, we leave them unlogged. Note that most of our selected housing characteristic variables represent some form of characteristics used by Burkhardt & Flyr (2019), Conklin, et al. (2020), or Cheng, et al. (2018). However, we also include additional variables none of the above authors possessed. Those are the garage area, the total number of fireplaces, and controls for the primary material used in home construction. But recall that such additional characteristics are deemed essential for the accuracy of hedonic models. This is especially true of the control of exterior wall construction material (Diewert, 2013, p. 25). Thus, our possession and implementation of such variables represent an advantage of our research. Additionally, all characteristics represent valid hedonic model choices (Diewert, 2013) (Haan & Diewert, 2013). There is one exception to the above; we do not include the number of bathrooms. This is because it is highly colinear with the total living area. Consider that the more bedrooms a home possesses, the more living area it will have. Thus, Denver County Assessors stopped recording such data post-June 30, 2018 (Erffmeyer, 2021). But Burkhardt & Flyr (2019), Conklin, et al. (2020), and Cheng, et al. (2018) all use pre-June 2018 housing characteristics data. Thus, all authors include bedroom count and its collinear counterpart living space. Hence, they most likely have differing degrees of collinearity present. Collinearity is an issue because “the OLS estimators have large variances and covariances, making precise estimation difficult.” More concerning is that large variances and covariances mean that “the confidence intervals tend to be much wider, leading to the acceptance of the “zero null hypothesis”…more readily” (Gujarati, et al., 2009, p. 348). When collinearity is present, you bias your results to over-rejection of the alternative hypothesis. Thus, we avoid this collinearity issue by following the Denver County Assessors' practice of omitting bedrooms and accounting for their impact via living area (Erffmeyer, 2021).

Now we come to our primary independent variables of interest: medicinal and recreational marijuana. We included the total amount of medicinal and recreational marijuana revenue generated in month *m-6* of year *y* that property *i* sold in. This was done to investigate our hypothesized mechanism. To our knowledge, the inclusion of marijuana revenue is novel in the hedonic literature. Yet the idea behind marijuana's insertion is not. We involve marijuana revenue for the same reason school quality is commonly included in hedonic models: it has the potential to impact the value individuals place on a home (Weimer & Wolkoff, 2001). First, suppose that dispensaries are investing in the Denver housing market for the aforementioned reasons. Consider a standard housing demand function as used by Jud & Frew(1986)

$$q = h(y, z) \tag{2}$$

Where q is the natural logarithm of the quantity of homes demanded, *y* is the natural logarithm of income, and *z* represents all other variables impacting demand. Now consider that the relationship between income and quantity demanded is positive (Jud & Frew, 1986) (Green & Hendershott, 1996). Further, suppose that the amount of marijuana revenue increases. But the quantity of marijuana revenue is also the income of dispensary owners. Thus, by equation (2), as marijuana revenue rises, so does the quantity of homes demanded by dispensaries. However, as income grows, it leads to increased demand for homes, as represented by a rightward shift of the demand curve. Yet the result of such a shift would be an increase in equilibrium Denver home prices, ceteris paribus (Rosen, 1974) (Jud & Frew, 1986). Thus, if there exists a statistically significant positive relationship between the amount of marijuana revenue and home prices, it will represent evidence in favor of dispensaries investing in Denver homes. That is, if either or both θ, ϕ are statistically significant and positive. We should note that the above logical chain of events is not without precedent. Zhang, et al. (2017) found that "the legalization of marijuana[in Colorado] created excess demand for real estate space[warehouses]" (Zhang, et al., 2017, p. 3). The result of such increased demand was exactly as we predict for homes: an increase in warehouse prices. The source of such excess demand was found to be marijuana growers (Zhang, et al., 2017). Additionally, recall that providers of federally illegal substances have previously used investment in real estate to launder their money and thus increase demand for homes in places like Miami, Florida, Columbia, and Bolivia (Navarro, 2013). Note that we are concerned with recreational marijuana's impact on the demand for homes and not the supply. This is because Cheng, et al. (2018) "Collectively, find evidence that recreational marijuana legalization leads to stronger housing demand and… no discernable effect on housing supply…." (Cheng, et al., 2018, p. 1598). Thus, we restrict ourselves to the above discussion of our proposed mechanism's demand-impacting features.

Notice that we include the amount of marijuana revenue generated six months before the home was sold (*m-6*). Our logic intuits that it is unlikely there will be an instant conversion of marijuana revenue into home purchases, as the home acquisition process often takes many months (Ellie Mae, 2020) (Zillow, 2021c) (Zillow, 2021b). Thus, it is likely that the typical time from possession of funds to ownership of the home is several months. Additionally, it will take time for the market to adjust to its new equilibrium home prices (Waugh, 1964). Hence, it is probable that the amount of marijuana revenue generated several months before a home sale is what would impact that home's value. However, it is worth confirming that this is the case. Thus, in appendix iv: ideal marijuana lag structure, we check the robustness of our primary results to alternative lag specifications. We find the optimal model to be one with marijuana revenue lagged by six months prior to a home sale. That is, the model which best explains the variations in the sale price of home *i*, according to the work of Baguley (2012). Additionally, using such a lag structure results in virtually no change in the signs and significance of our parameters. The only difference of real import is a slight decrease in the magnitude of the coefficient on recreational marijuana. This makes sense because there was no recreational marijuana revenue before January 2014. Thus, each lag introduces more zero values into the analysis and thus decreases the magnitude of the coefficient. Yet, our lagged model significantly outperformed the unlagged one. Together, all the above makes us confident in the lag structure we employ for our primary evaluation of equation (1).

The inclusion of neighborhood dummies was undertaken to account for locational neighborhood characteristics' impact on home values. For instance, amenities such as a park or disamenities like local crime. Recall from our literature review that dispensaries in Denver neighborhoods were found to lower crime (Brinkman & Mok-Lamme, 2019) (Burkhardt & Goemans, 2019). On top of this, Boggess, et al. (2014) found that Colorado dispensaries tend to locate in neighborhoods with elevated crime levels. Hence, we must be able to account for possible neighborhood effects on home values. Also, remember that "the ability to locate a home to the neighborhood level, has been shown to improve the accuracy of hedonic models by roughly 34%" (Oust, et al., 2020, p. 197). Finally, remember that Burkhardt & Flyr (2019) and Conklin, et al. (2020) employed neighborhood fixed effects.

There is mixed evidence when it comes to the seasonality of home prices. However, little doubt exists regarding the seasonality of demand for homes. Yet, whether seasonal demand fluctuations cause seasonal variations in home prices appears uncertain (Diewert, 2013). For instance, Meese & Wallace (1991) find "only weak seasonality" of home prices (Meese & Wallace, 1991, p. 326). Additionally, Schiller & Case (1987) find little seasonality effect when one properly accounts for changes in the types of homes sold in a given year (Shiller & Case, 1987). They argue that the kind of homes demanded changes at different times of the year. For instance, wealthier families seek to relocate in the summer between school years. Thus, larger homes in good school districts would be most demanded during summer. Yet, other cheaper home styles would dominate at other times of the year. Thus, Schiller & Case (1987) posit that there is no seasonality in price as much as seasonality in the type and cost of the home demanded. However, Prasad & Richard (2008) report that the median sale price of single-family homes in Australia, America, Canada, and New Zealand all exhibit seasonality. This is because of seasonal home demand, as opposed to seasonal supply. However, when one accounts for between area seasonality, home price seasonality seems to disappear at a national level (Prasad & Richards, 2008). Thus, seasonality appears to be less of a concern on a national level. "However, at lower levels of aggregation it would be useful to check whether any seasonality in prices is present…" (Diewert, 2013, p. 28). This makes sense when one considers the work of Reichert (1990). There it was found that the presence of home price seasonality in America depended on the region. Specifically, colder climates "where home buying (and hence home building) is often postponed to the spring and summer months" tended to exhibit home price seasonality. However, warmer climates like the American South do not see such home price seasonality (Reichert, 1990, pp. 379,384-86,388). Thus, regional seasonality may be a concern, but nationally the separate regions are balancing each other out. Hence, national home price seasonality virtually disappears. But we are looking at a single metropolitan county. Thus, we follow Burkhardt & Flyr (2019) and include monthly fixed effects. Such a decision is supported by Oust, et al. (2020). Their analysis is similar to ours in that it uses a hedonic model to look at home values in one metropolitan area. They too deemed it wise to account for seasonality of their housing market (Oust, et al., 2020). Further supporting our decision is the above-mentioned work of Reichert (1990), who found that home price seasonality was one of the "common factors" impacting home values in the American West (Reichert, 1990, p. 386). Finally, Ngai & Tenreyro (2014) find that "US cities tend to display higher seasonality" than non-metropolitan areas (Ngai & Tenreyro, 2014, p. 3992). Thus, we feel well justified in our inclusion of month-fixed effects to pick up the seasonality of home prices.

Finally, we followed Burkhardt & Flyr (2019) by including year-fixed effects. Such a decision was made because it is often the case that "the difference in transaction prices [of a home] between two dates will be affected only by the intervening time period." (Case, et al., 1991, p. 288). That is, when one properly accounts for the changes in a home's characteristics over time, then the passage of time itself is one factor that also must be accounted for. This needs to be done if for no other reason than consumer tastes in homes change over time (Shiller & Case, 1987). Thus, we have included year-fixed effects to control for time-dependent factors impacting home values. Year-fixed effects also add to neighborhood-fixed effects in controlling for crime. We discussed how neighborhood crime could be accounted for with neighborhood-fixed effects. Yet we also must account for changes in crime over time (Brinkman & Mok-Lamme, 2019) (Burkhardt & Goemans, 2019) (Burkhardt & Flyr, 2019) (Conklin, et al., 2020). This is another benefit year-fixed effects can provide. Now interacting neighborhood and year-fixed effects might have been a more direct way to control for possible crime impacts. However, Cameron & Miller (2015) warn against such an approach to "cluster-specific fixed effects" (Cameron & Miller, 2015, p. 356). Hence, separate neighborhood and year-fixed effects were the most practical approach.

Cameron & Miller (2015) introduces perhaps the most crucial reason for the inclusion of all the above controls of neighborhood, month, and year fixed effects: to address potential spatial and serial autocorrelation of our data. In short, the use of "cluster-specific fixed effects" is one of the best ways to account for potential spatial and serial relationships that our data might suffer from (Cameron & Miller, 2015, p. 356) (Gujarati, et al., 2009) (Stock & Watson, 2007). This concept is taken up in much more detail in appendix iii: cluster robust errors.

Finally, in conjunction with the above-discussed "cluster-specific fixed effects," we employ a Cameron & Miller (2015) heteroskedasticity few-clusters robust, cluster robust error term. Controls of neighborhood, month, and year fixed effects go a long way toward controlling for any potential spatial and serial correlation in our data. However, we know from Cameron & Miller (2015) that "cluster-specific fixed effects" are not always sufficient to deal with pernicious autocorrelation. This is the case for serial autocorrelation, which likely arises from the time series nature of our unaltered marijuana revenue data. Additionally, the net migration, average wages, and total employment data are all initially time series in nature (Stock & Watson, 2007). The sources of such data are discussed in more detail in the upcoming data section. Further, we thoroughly examine the theoretical motivation and empirical superiority of Cameron & Miller (2015)'s heteroskedasticity few-clusters robust, cluster robust errors in appendix iii: cluster robust errors. In short, we have included heteroskedasticity, few-clusters robust, cluster robust errors to account for any possible heteroskedasticity and remaining serial autocorrelation present in the data (Stock & Watson, 2007). Further, following the methods of Greene (2012), we carried out the requisite additional analysis to ensure that all remaining OLS assumptions were satisfied. Each assumption was met. Thus, we can safely follow the vast body of literature and employ OLS as our means of estimating equation (1) , as well as equations (3) and (4) to be discussed.

Robustness Checks

To begin our conversation of economic robustness checks, recall our hypothesis that dispensary owners might be Cheng, et al. (2018)'s investors who are driving up demand and thus home prices. The motivation for such behavior being a lack of banking access. However, there are several other prominent explanations for an association between recreational marijuana legalization and the 6% increase in home values that Cheng, et al. (2018) found.

The first alternative is that the legalization of recreational marijuana would represent an amenity to workers. Thus, people would migrate to Denver County to access the amenity. This is what Zambiasi & Stillman (2020) concluded in their research. They found legalization of marijuana led to a 3.2% increase in the population of Colorado by 2015. They stated that the legalization of marijuana was viewed as an amenity and thus initially drew immigrants to the state (Zambiasi & Stillman, 2020). Consider figure 2.

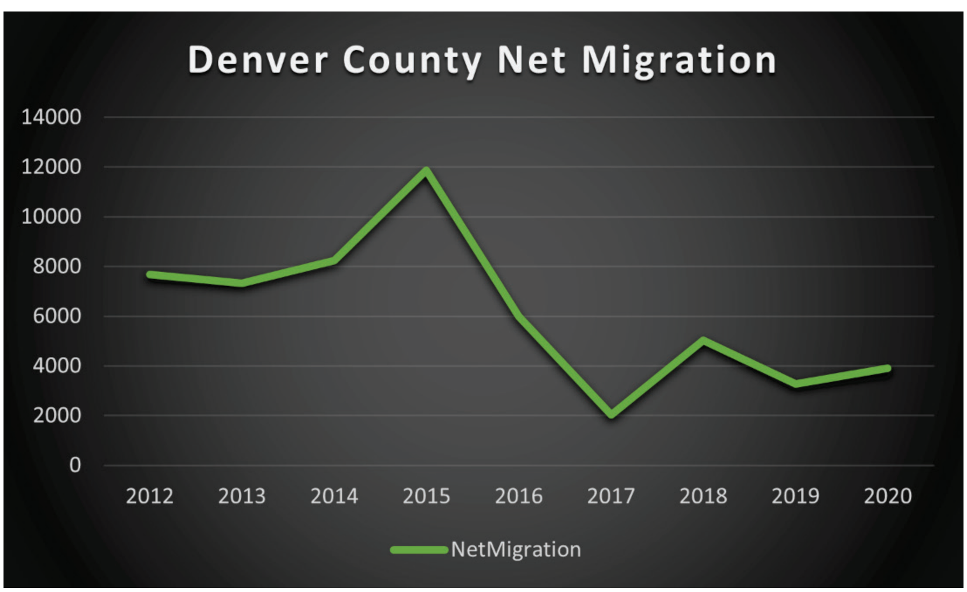

Figure 2. Denver County Net Migration Data From (State Demography Office, 2021)

We see that in the year recreational marijuana was legalized, there was an uptick in net migration to Denver County (Conklin, et al., 2020). This is in keeping with the research of Zambiasi & Stillman (2020). However, as more states legalized recreational marijuana, Colorado lost its "first mover state" status. Thus, a substantial dip in net migration to Denver County post-2015 (Zambiasi & Stillman, 2020, p. 678). For one thing, Washington began the sale of legalized recreational marijuana in July 2014 (Hudak, 2020). Hence, it is dubious if marijuana-induced population growth could exert constant positive impacts on home prices. Still, we need to account for changes in population over time, as they can impact home prices (Rosen, 1974) (Zambiasi & Stillman, 2020). Thus, we include net migration data in equation (3). This will allow us to ensure that the increase in demand witnessed by Cheng, et al. (2018) is not coming from migrants moving into the area, thereby increasing home demand and consequently prices.

Intertwined with migration's ability to explain increased housing prices is the notion of average wages. Consider the work of Zambiasi & Stillman (2020). They claim that "potential migrants view legalized marijuana as a positive amenity," at least until the end of 2015 (Zambiasi & Stillman, 2020, p. 11). However, they are silent on the views of firms regarding the legalization of marijuana. Yet to determine the general equilibrium outcome of the Roback model they cite, one needs to understand the firms' view of the amenity. If an amenity is "unproductive" for firms, we should see a decrease in the equilibrium wage paid to Denver workers (Roback, 1982). "Unproductive" amenities are ones that increase firms' costs, such as "clean air because firms must spend resources to use nonpolluting technology" (Roback, 1982, p. 1261). Thus, consider that "Costs[for firms] such as identifying, hiring, and retaining capable employees while maintaining a drug free environment are increasing in time and money as more people are able to use marijuana legally." Further, "Other potential costs relate to lost productivity, increased absenteeism, workplace accidents, and litigation costs. Research has shown that marijuana use increases the costs related to all of these…as more people are permitted to legally use marijuana" (Elliott, et al., 2019, p. 21). Thus, marijuana legalization most closely fits Roback's definition of an "unproductive amenity" for firms (Roback, 1982, p. 1260).

But given the above, if "potential migrants view legalized marijuana as a positive amenity," then Roback (1982) implies that "wages should be lower, while the change in rent is uncertain" (Zambiasi & Stillman, 2020, p. 11) (Roback, 1982, p. 1262). Thus, we must look at the trends of average wages in Denver County, not rents, to determine the possibility of legalized recreational marijuana being a positive amenity for workers. Note that we employ average hourly earnings data because “this measure is perhaps the closest of our measures to the concept of wages” (Knotek & Zaman, 2014, p. 1). Hence consider figure 3.

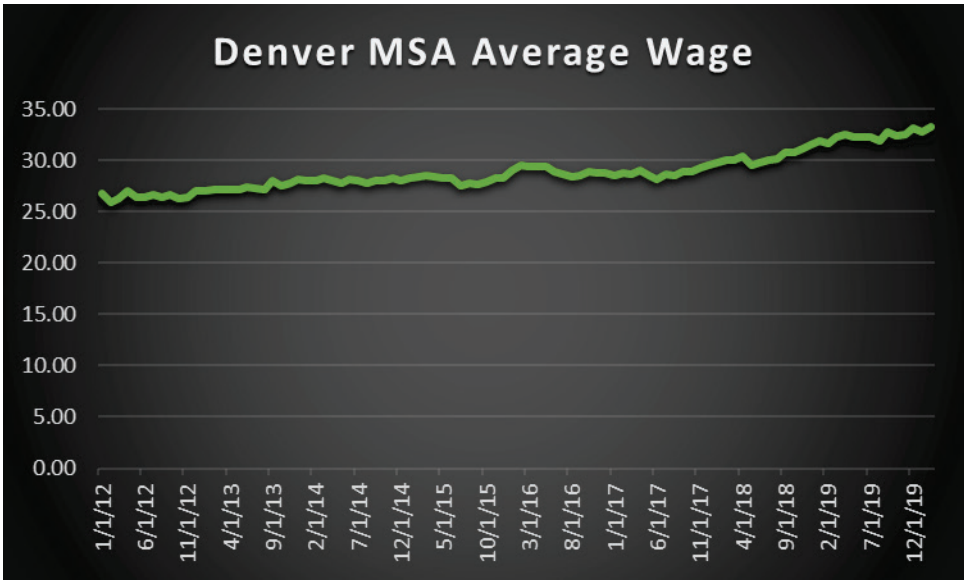

Figure 3. Denver MSA Average Wage Data From (Bureau of Labor Statistics, 2022a)

Average wages are increasing over time. However, there was a slight decrease in the average wage from the end of December 2013 through most of 2015. Yet recall figure 2 showed an uptick in net migration for this period. Finally, remember that Zamibiasi & Stillman (2020) indicate that the observed results of increased migration to Colorado might well dissipate after 2015. Together, it seems that if the recreational legalization of marijuana was a positive amenity for workers, that status appears to be short-lived. The overall trend of increasing average wages, together with the Roback model, speaks against the notion that legalized recreational marijuana is a positive amenity throughout our sample period (Roback, 1982). However, it could be that while the nominal average wage has increased, the real income workers received has decreased after the legalization of recreational marijuana. In this spirit, consider figure 4. Here we see the same trend of increasing real per capita income for Denver MSA residents. This is visible both before and after the legalization of recreational marijuana.

Considering figure 3 and figure 4 together, there seems scant evidence to support the idea that wages decreased over the time in question. In fact, both nominal wages and real income per capita increased. But again, we should see reduced wages if legalized marijuana represents a positive amenity for workers. Thus, it seems that

Zambiasi & Stillman (2020) are correct in restricting their statement of marijuana legalization, representing an amenity for workers to the year 2015 (Zambiasi & Stillman, 2020). If the legalization of marijuana did represent a positive amenity, Roback (1982) indicates that we should see both increasing net migration and decreasing wages. But beyond 2015, we see the very opposite of this: Increasing wages and decreasing net migration. Yet, it is still worthwhile to include controls for net migration and average wages in our test of the robustness of equation (1). Such a test is carried out via equation (3).

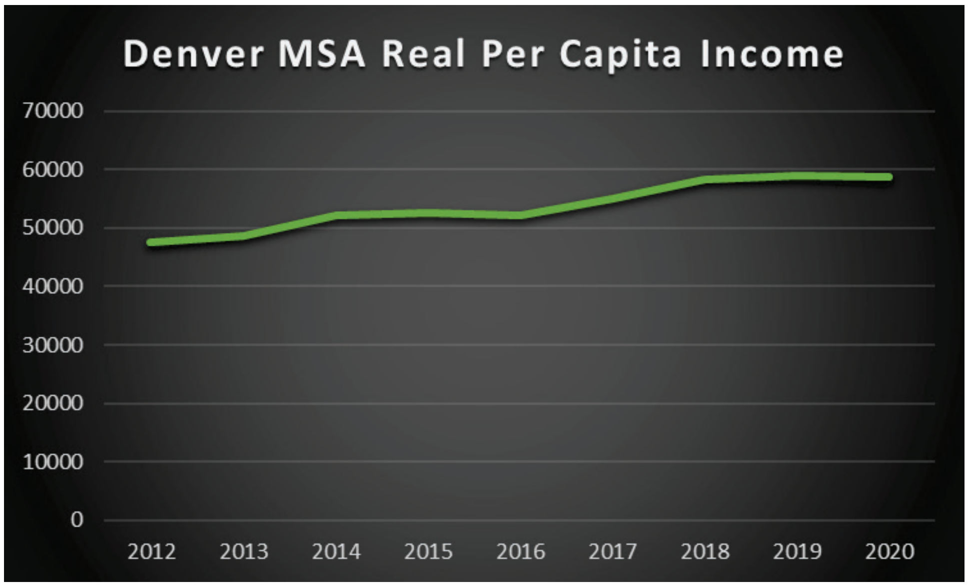

Figure 4. Denver MSA Real Per Capita Income Data From (Bureau of Economic Analysis, 2022)

However, it is almost indisputable that the legalization of marijuana "created jobs" for Denver County residents (Hudak, 2020, p. 203). Now whether enough jobs were created to increase demand for single-family homes is the real question. Thus, consider figure 5 that follows. We see that seasonality aside, there is a steady upward trend in the number of employed Denver County citizens. However, we do not see a significant uptick in employed individuals. Such a sudden increase would be expected if the legalization of marijuana led to substantial growth in the number of jobs and those employed. However, it is worthwhile to include controls for the number of employed Denver citizens. Thus, such a term is present in equation (3).

Considering the above potential alternative explanations of the association between legalized recreational marijuana and increasing home prices, consider equation (3). It employs the three data sources needed to test the robustness of equation (1)'s results to the inclusion of the natural log of net migration, average wages, and the number of employed citizens of Denver.

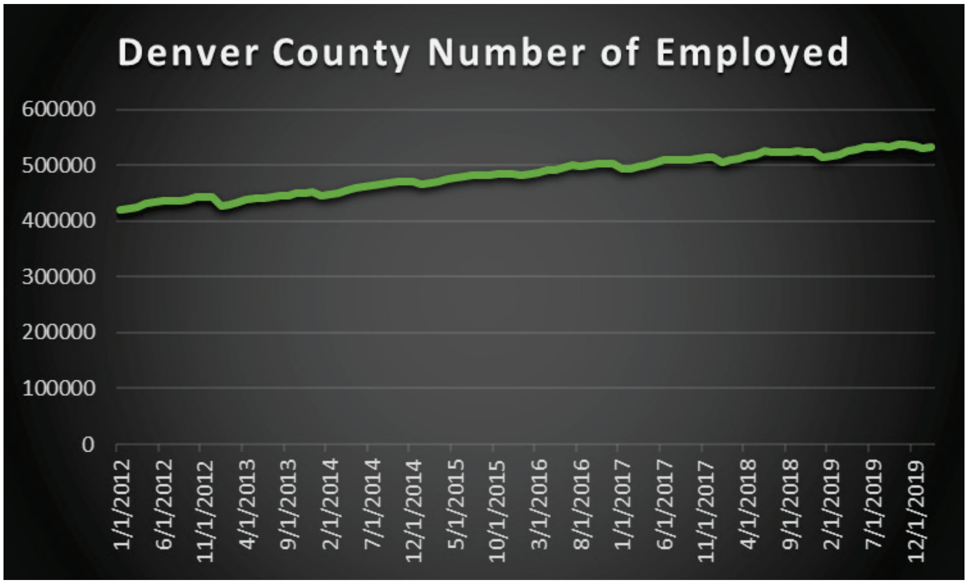

Figure 5. Denver County Employment Data From (Bureau of Labor Statistics, 2022b)

$$
\begin{aligned}
ln(y_{imy}) = \alpha + \sum_{j=1}^{J} \beta_j ln\,(QC_{jimy}) + \sum_{k=1}^{K} \delta_k QD_{kimy} + \sum_{e=1}^{E} \xi_{\,e} ExtWls_{ie} + \theta\, ln(MedRev_{(m-6)y}) \\
+ \phi\, ln(RecRev_{(m-6)y}) + \lambda \ln(NetMig_{my})\, \kappa \ln(AveWage_{my}) + \gamma \ln\,(Emp_{my}) \\
+ \sum_{n=1}^{N} \eta_n NBHD_{in} + \sum_{m=1}^{M} \mu_m Month_{im} + \sum_{y=1}^{Y} \psi_y Year_{iy} + \epsilon_{imy}
\end{aligned}
\tag{3}
$$

Where $\ln(AveWage_{my})$ is the natural log of the average wage in month *m* of year *y*, $\ln(NetMig_{my})$ represents the natural log of net migration occurring in month *m* of year *y*, and $\ln\,(Emp_{my})$ expresses the natural log of the number of employed individuals in Denver County in month *m* of year *y*. Equation (3) thus represents our attempt to account for the previously discussed alternatives to our hypothesized mechanism of home price increase. Additionally, we chose to log our control variables, as doing so is helpful for interpretation purposes (Gujarati, et al., 2009).

However, we wish to test further the robustness of our hedonic model estimates of equations (1) and (3). Thus, as aforementioned, we will carry out a robustness check of our primary analysis from equations (1) and (3) using the alternative approach of Case, et al. (1991). Specifically, we will employ the hedonic portion of the Case, et al. (1991) "hybrid" method. Hence, consider equation (4):

$$YAD_{imy} = \alpha + \sum_{j=1}^{J} \beta_j ln\ (QC_{jimy}) + \sum_{k=1}^{K} \delta_k QD_{kimy} + \theta\ ln\big(MedRev_{(m-3)y}\big) + \phi\ ln(RecRev_{(m-3)y})$$

$$+ \lambda \ln\big(NetMig_{my}\big) + \kappa \ln\big(AveWage_{my}\big) + \sum_{n=1}^{N} \eta_n NBHD_{in} + \epsilon_{imy} \qquad (4)$$

Where, $YAD_{imy} = \ln\big(y_{imy}\big) - \ln\big(HPI_{my}\big)$, HPI_{my} is the Case Shiller home price index value in month *m* of year *y*. Otherwise, the remaining terms are as described in equations (1) and (3) above.

Our aim with the above is to provide an alternative method of accounting for the change in home values over time. This is accomplished by subtracting the natural log of the home price index from the natural log of the sale price (Case, et al., 1991). In equations (1) and (3), this was achieved with month and year dummies. However, it is done here via the home price index subtraction. This works because home price indices are constructed by exponentiation of the time dummy coefficients from the hedonic model (Haan & Diewert, 2013). The results of equation (4) are to be found alongside those of equations (1) and (3) in table 2. Note that the employment term is not included. This is because our results in table 2 indicate that such a term is not justified in our final model.

Data

This section is broken down into several subsections. We commence with a discussion of the logic behind our choice of time period, geographic region, and unit of analysis. Next, we examine our data's sources, alterations, and advantages. Finally, we present our summary statistics.

Time Period, Geographic Region, and Unit of Analysis

Our empirical analysis employs several data sources, spanning July 1st, 2012, to June 30th, 2020. However, our final merged dataset covers January 1st, 2014, to February 29th, 2020. We chose this period for several reasons related to maintaining the implicit assumption "that attribute prices remain stable" (Meese & Wallace, 1991, p. 312). This is important when estimating a single coefficient for each housing characteristic (Haan & Diewert, 2013).

Our first data set begins January 1st, 2014, with the commencement of legalized recreational marijuana sales in Colorado (Colorado Department of Revenue, 2019). Such a start date is beneficial for another reason: we avoid the volatile home prices of the Great Recession. The Great Recession officially lasted from December 2007 through June 2009. However, its effects were felt several years after its formal end (Rich, 2013). Yet, by the 3rd quarter of 2012, the Housing Price Index for Colorado shows home values rebounding to pre-recession levels. Thus, the Great Recession's impact on home prices dissipated before legalized recreational marijuana was first sold in Denver County (FHFA, 2020) (Conklin, et al., 2020). The commencement of our sample period differs from the existing literature. Conklin, et al. (2020), and Burkhardt & Flyr (2019) began in 2008, and Cheng, et al. (2018) in 2010. But this means they include home sales still impacted by the Great Recession. Thus, their home values are likely lower than they would typically be. Hence, the true impact of characteristics on sale price could be underestimated. Further, all the authors use a difference-in-difference methodology. But then, the depressed characteristic values could be biasing their results in favor of an outsized impact of legalization on home prices. Such a bias might be made worse by the fact that Cheng, et al. (2018) and Conklin, et al. (2020) only have one year of post-legalized recreational marijuana data (Cheng, et al., 2018) (Conklin, et al., 2020). However, Burkhardt & Flyr (2019) obtain similar results to Conklin, et al. (2020) with a much larger post-legalization period. Yet, their work also appears to include the depressed home values of the Great Recession (Burkhardt & Flyr, 2019).

Secondly, we needed to avoid the impacts of the Covid-19 pandemic. On March 11th, 2020, travel bans and other U.S. market-affecting restrictions commenced. Additionally, the World Health Organization declared Covid-19 a pandemic on that date (Katella, 2021). But we need to exclude any possible effects from this once-in-a-lifetime shock. In fact, Covid 19 would significantly alter prices and demand for both Denver County housing and marijuana. Specifically, in mid-March, national median home prices fell drastically, only to rebound to some of the highest levels in over a decade (Katz, 2021). Additionally, the pandemic and its long periods of isolation greatly increased global demand for marijuana products (Bures, 2020) (Khan, 2021) (Yakowicz, 2021). March 2020 was when increased demand for marijuana products made its impact felt in Denver County (Colorado Department of Revenue, 2021). Thus, for all the above reasons, we selected February 29th, 2020, as the end date for our data. We thus minimize any exogenous effects the pandemic might have had on our analysis. Finally, all our records have a monthly periodicity. Fortunately, such a unit of time is well-suited for hedonic home price modeling (Diewert, 2013).

Next, let us consider our geographic area of analysis: Denver County. We investigate Denver County for several reasons. Firstly, Cheng, et al. (2018) found metropolitan areas were driving the trend of marijuana legalization and its associated "6% increase in home values" (Cheng, et al., 2018, p. 1). Thus, our county of analysis needed to be a metropolitan one. Secondly, we wanted to focus on one county. "Economists have long recognized that housing markets are geographically localized; thus, housing price indices are typically estimated for a geographic area no larger than the county or metropolitan area…." (Case, et al., 1991, p. 287) Hence, by considering one sub-state level area of analysis, we follow in the footsteps of a host of previous home price modeling literature, including Case & Quigley (1991), Case, et al. (1991), Quigley (1995), Hill, et al. (1997), Case, et al. (2006), Conklin, et al. (2020), Burkhardt & Flyr (2019), and Oust, et al. (2020). Thirdly, Denver County possesses sufficient housing characteristics for effective hedonic analysis. In fact, Denver has some of the most robust housing data in the nation (Erffmeyer, 2021). Fourthly, while "many believe [Denver County] to be drastically different from the rest of Colorado," Cheng, et al. (2018) showed that it is representative of all metropolitan areas of Colorado (Cheng, et al., 2018, p. 22). Thus, we feel confident in our consideration of Denver County. It appears both valid and generally representative of the overarching trends of legalization of marijuana and home prices in metropolitan areas of Colorado. Additionally, Denver County was used by both Conklin, et al. (2020) and Burkhardt & Flyr (2019) in their analysis.

Finally, let us examine our unit of analysis. We have restricted our investigation to single-family homes for two main reasons. Firstly, considering all residential property types in a single analysis is generally ill-advised. This is because "Economists have…recognized that particular types of housing (single-family detached, single-family attached, multifamily) constitute individual housing markets;…and the assumption is explicit or understood that the estimated price…is only valid for that type of housing" (Case, et al., 1991, p. 287) Basically, varying property types can have differing price impacting characteristics (Haan & Diewert, 2013, p. 56) (Erffmeyer, 2021). For instance, the view provided by a condominium substantially affects its value. Suppose one condominium is on the second floor and thus provides a superior view of the Rocky Mountains. Consider an identical condominium situated on the first level of the same building. The condominium with the better view will be more valuable, all else equal. Yet single-family homes typically have a similar number of stories. Thus, the view is likely to be comparable in adjacent properties. Therefore, Denver County Assessors find view characteristics impactful for condominium sales but not for single-family homes (Erffmeyer, 2021). Thus, considering all residential properties at once is akin to comparing apples to oranges. Hence, it is best to consider only one type of residential property. Doing so also gives our research more precision than Cheng, et al. (2018) and Burkhardt & Flyr (2019). Both authors combined residential property types. As it behooves us to consider only one property type, we have selected single-family homes. We chose single-family homes because they comprise the majority of residential properties sold in Denver County during our sample period (Erffmeyer, 2021) (Schechter, 2020) (REDFIN, 2021). Consider February 2020. That month, single-family homes accounted for roughly 49% of all homes sold in Denver County. Condominiums were next at around 31%, while townhomes made up just 19% of all sales. Multifamily homes accounted for the remaining 1% of residential properties sold. Figures 6-9 attest to the above trend's presence in all remaining months of our sample period.

In summary, we must consider a distinct type of residential property, and single-family homes far outnumber other individual residential property type sales. Finally, our decision to look at single-family homes is one supported by the existing literature on hedonic analysis (Dorsey, et al., 2010) (Shiller & Case, 1987) (Berry & Bednarz, 1975) (Clap & Giaccotto, 1992) (Case, et al., 1991) (Case & Quigley, 1991). Additionally, by considering single-family homes, we follow the research of Conklin, et al. (2020).

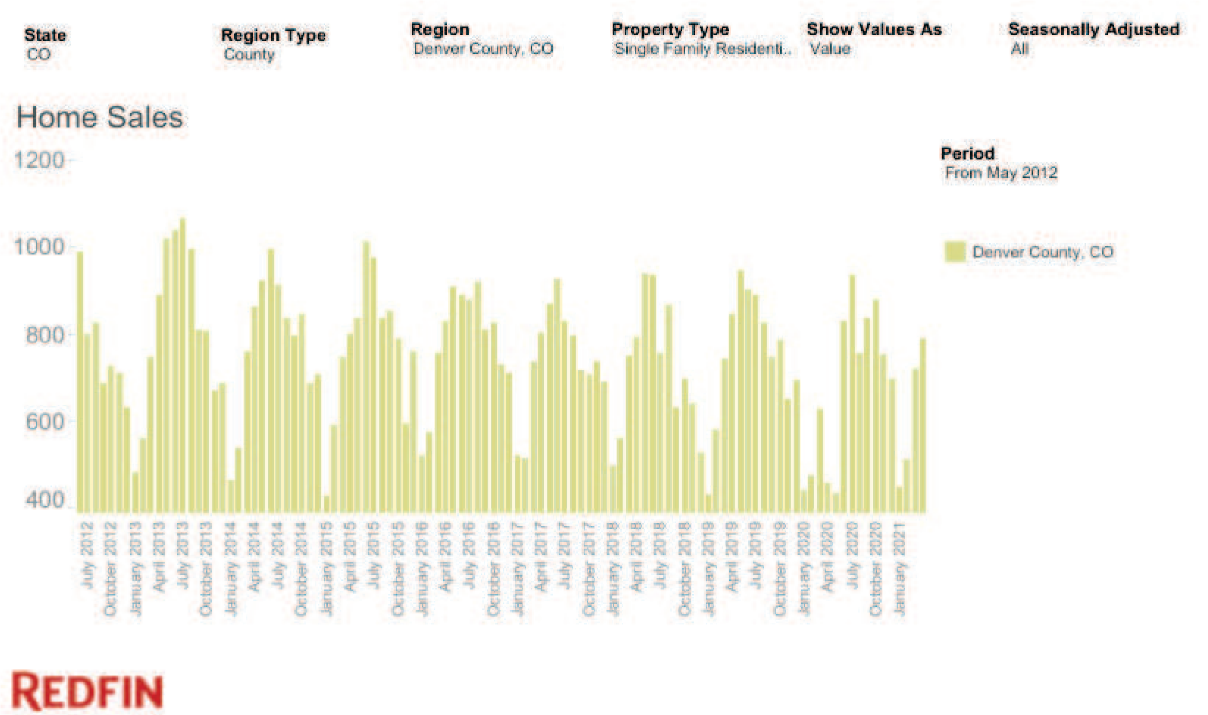

Figure 6. Seasonally Adjusted Denver Single Family Home Sales (REDFIN, 2021)

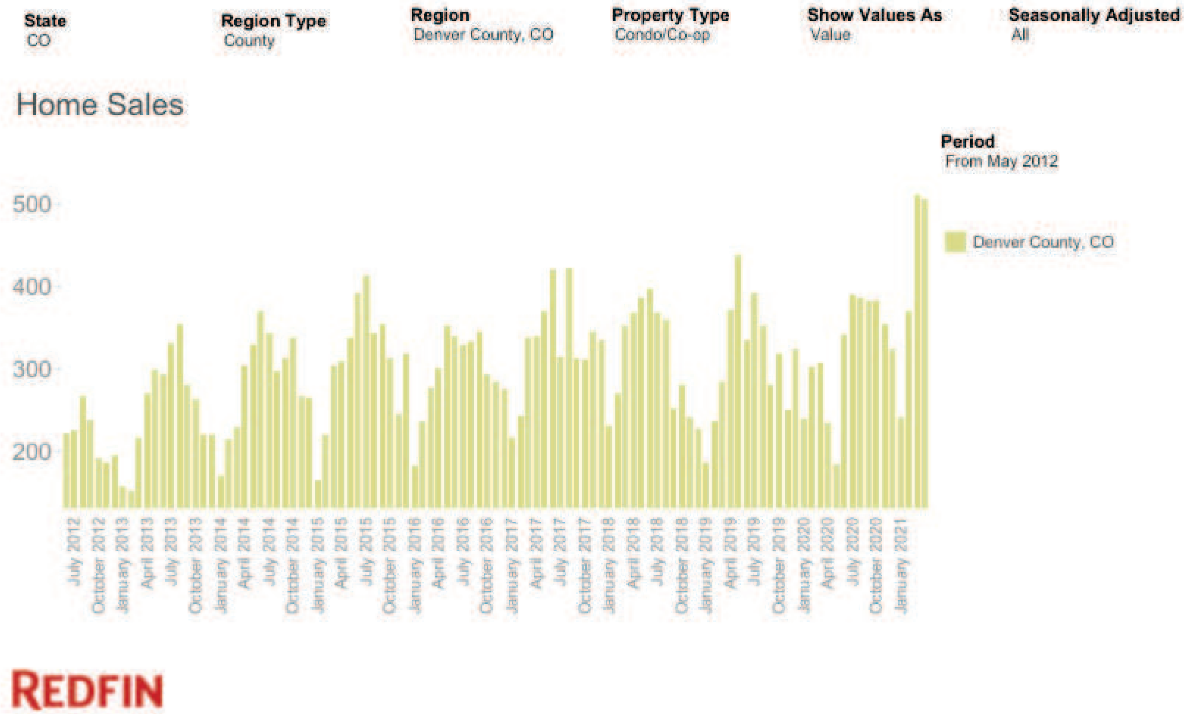

Figure 7. Seasonally Adjusted Denver Condominium Sales (REDFIN, 2021)

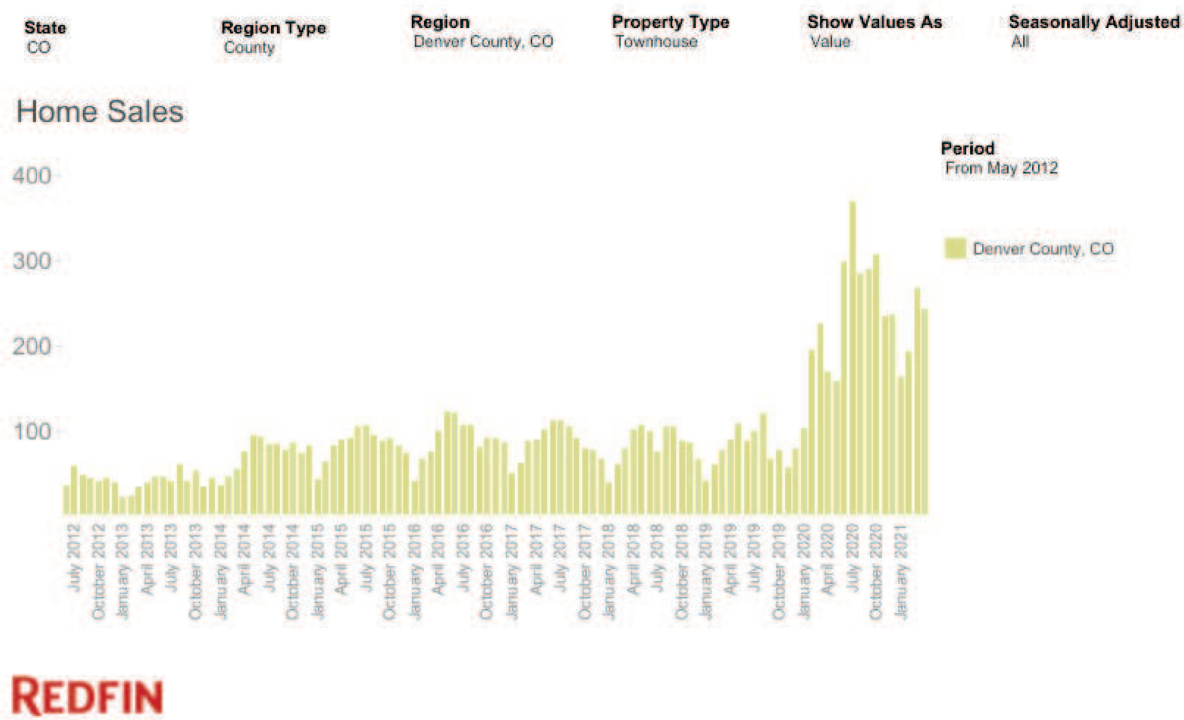

Figure 8. Seasonally Adjusted Denver Town Home Sales (REDFIN, 2021)

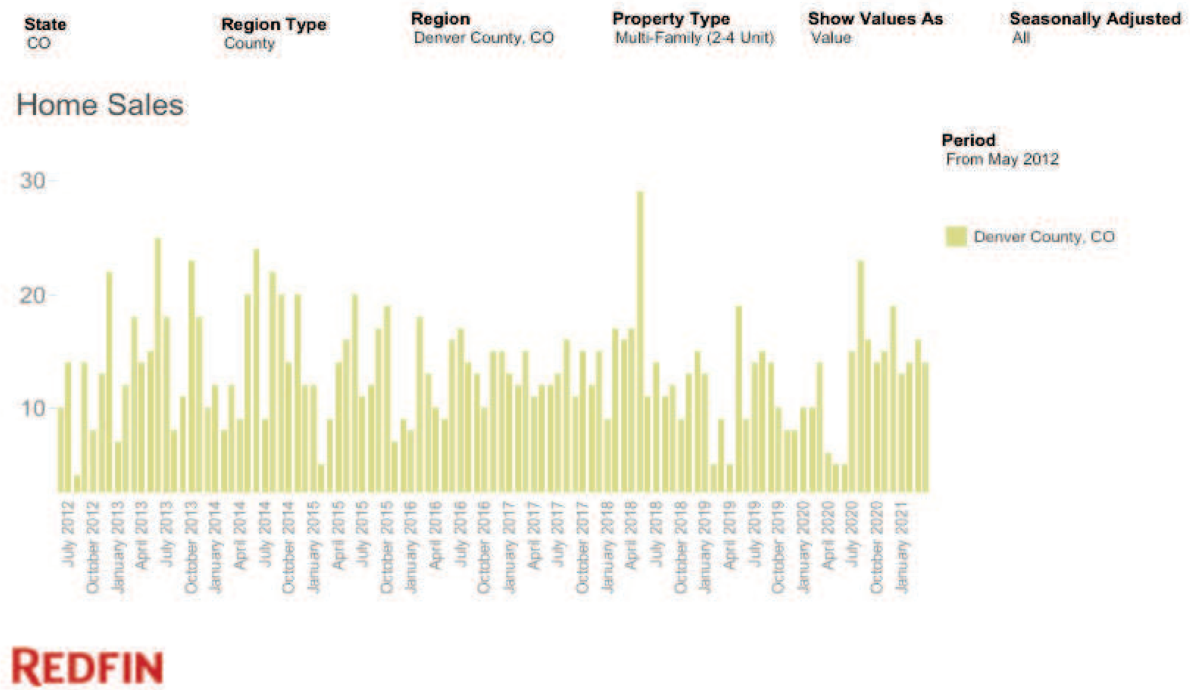

Figure 9. Seasonally Adjusted Denver Multi-Family Home Sales (REDFIN, 2021)

Sources, Alterations, and Advantages of Data

Now consider the sources of our data, the alterations it has undergone, and its advantages. We begin with single-family residential home data concerning characteristics and sale data. Such records originated with the Denver County Assessors. The data was acquired for all single-family residential homes sold in Denver County, Colorado, between July 1st, 2012, to June 30th, 2020. However, we limit ourselves to the period from January 1st, 2014, through February 29th, 2020. The housing characteristics and sales data were carefully selected to concern only arm's length home sales. The IRS tax code states, " arm's length transaction is a transaction where there is no bargain or gift element…" (IRS, 2019). Thus, we consider only homes selling for $30,000 or more, as "the majority of "sales" …less than $30,000 would not normally be considered a true sales transaction" (Conklin, et al., 2020, p. 11). Such a lower bound for arm's length home sales is common in the literature (Cheng, et al., 2018) (Burkhardt & Flyr, 2019). For a more detailed discussion of the Denver County Assessors data, see appendix i: housing data discussion.

Unlike previous literature, our housing data is not directly nor indirectly (Corelogic) obtained from the Denver Open Data Catalog (Cheng, et al., 2018) (Conklin, et al., 2020) (Burkhardt & Flyr, 2019) (Beavers, 2020)

(Denver County, 2021). The concern with the Denver Open Data Catalog's housing data is that it lacks historically accurate housing characteristics (Erffmeyer, 2021). Suppose home X sold in 2016 without a garage. Further, suppose the new owner added a garage after purchasing home X. Then home X was resold in 2020. Hence, there was no garage for the first sale of home X. Yet, for the second sale, a garage is present. However, the Denver Open Data Catalog only considers the characteristics of a home at its last time of purchase. It then imposes those characteristics for all previous sales of that home. Thus, the Denver Open Data Catalog would record a garage as being present for all sales of home X. But this was not the case for the sale in 2016. Hence, models using the Denver County Open Data Catalog data will likely underestimate the impact of all the other housing characteristics on the sale price. To see this, let your model assume the presence of a nonexistent garage. But then the share of the home's price attributed to the actual characteristics present must be diminished. Fortunately, our housing data is historically accurate. That is, a home's recorded characteristics are accurate as of the date of sale (Erffmeyer, 2021). The use of historically accurate housing characteristics data is a major contribution of our research to the existing canon of literature on marijuana legalization and home prices in Colorado (Burkhardt & Flyr, 2019) (Cheng, et al., 2018) (Conklin, et al., 2020).

A further advantage of our housing data is that we possess information on many price-influencing characteristics. The existing literature mainly looked at the essential attributes of; age, location, number of bedrooms, bathrooms, lot size, and number of stories a home had (Burkhardt & Flyr, 2019) (Conklin, et al., 2020) (Cheng, et al., 2018). However, we possess data on all the housing characteristics used by previous literature, plus supplementary characteristics. Recall that two of the main additional characteristics' we possess are the effective age of the property and the primary material the home is constructed from. We have other novel home attribute data as well. Specifically, the area of any garage present and the number of fireplaces. Our abundance of characteristic data is not surprising considering the thoroughness of the scope of housing metrics collected by the Denver County Assessors. They are world-renowned for it (Erffmeyer, 2021).

Now recall that our housing data contains detailed sale price information. Such sale price data includes the nominal sale price of the home at the time of sale, minus any concessions. Also, remember that the ability to account for various forms of depreciation is vital to acquiring accurate hedonic model estimates (Diewert, 2013) (Hill, et al., 1997). Thus, our adjusted sale price measures have advantages over the existing literature. Such research employed either the nominal sale price of the home or the constant 2010-dollar value of the house. Further, our study is the first we are aware of to consider seller concessions (Burkhardt & Flyr, 2019) (Cheng, et al., 2018) (Conklin, et al., 2020) (Erffmeyer, 2021). Yet, by omitting seller concessions and depreciation, the previous authors' sale price data might underestimate the impact of their housing characteristics on the home's sale price. Consider home Y and let it sell for $500,000. But suppose it has a depreciating factor that reduces the price the owner could get by 5%. Thus, the sans-depreciation sale price would be $525,000. Hence, the true impact of home Y's characteristics on the sale price is underestimated by $25,000 (Erffmeyer, 2021). But then, previous literature might overestimate the effect of marijuana legalization on home prices.

The lack of depreciation and the absence of historically accurate housing characteristics contribute to the same possible issue: a potential double underestimation of the true impact of housing characteristics on home value. But again, if you underestimate the impact of housing characteristics on that home's sale price, you might well be overestimating the impact of the legalization of marijuana. Conversely, previous research may overestimate house sale prices by failing to account for home value concessions. Thus, overestimation of the impact of a home's characteristics may occur (Burkhardt & Flyr, 2019) (Cheng, et al., 2018) (Conklin, et al., 2020). Hence, our novel dataset contributes much to the research on marijuana and home prices. Finally, it is often the case that sales records originate from reality companies. But these records contain only partial data on all the homes sold in the area. Notably, it includes only the homes sold by a given reality company. But our data is thus advantageous because it is obtained from the Denver County Assessors. Therefore, it contains the sales of all single-family residences in that area. Consequently, we follow in the footsteps of Clapp & Giaccotto (1992) regarding our inclusivity of all property sales in our county of analysis (Clap & Giaccotto, 1992). However, we are not the first to recognize county assessors' data suitability for home price modeling (Case, et al., 1991).

We collected, combined, and modified three distinct sources of marijuana sales tax records for our second primary dataset. The first records contained the total revenue generated by the 2.9% medicinal marijuana sales tax of Denver County. It covered January 1st, 2014, to June 30th, 2020. Thus, the monthly tax revenue reported here represents 2.9% of the total medicinal marijuana revenue sold during a given month. Our second data source covered the total revenue collected from the Recreational Marijuana State Sales Tax in Denver County. It covered January 1st, 2014, to June 30th, 2017. The rate of this tax was 2.9 %. Our third data set is a record of total monthly marijuana revenue generated by the Recreational Marijuana State Sales Tax of Denver County. The records spanned July 1st, 2017, to June 30th, 2020. Two separately recorded data sources for the Recreational Marijuana State Sales Tax exist. This is because the tax rate increased from 2.9% to 15% on July 1st, 2017. The revenue of this dataset represents 90% of the 15% Recreational Marijuana State Sales tax collected. Finally, all the above data sets were obtained from the Colorado Department of Revenue (Colorado Department of Revenue, 2021). Together, the above allowed us to calculate the total monthly medicinal and recreational marijuana sales revenue for Denver County. For a more in-depth discussion of the creation of our marijuana revenue dataset, see appendix ii: marijuana data discussion.

Recall our work is the first we are aware of to analyze a possible mechanism by which recreational marijuana legalization could be associated with increased home prices in Denver, Colorado. All previous authors put forward suggestions as to why the patterns they observed might be occurring. Yet none investigated such postulations. Further, our hitherto-discussed mechanism appears unique among the existing literature. Thus, our use of marijuana revenue records seems novel in the current research on the subject of marijuana and Colorado home prices (Cheng, et al., 2018) (Conklin, et al., 2020) (Burkhardt & Flyr, 2019).

The third data set used for our analysis is the seasonally adjusted Case Shiller Single Family Home Price Index for Denver County, Colorado. We obtained such data to conduct a robustness check of our primary hedonic results in table 2. Such a check will be carried out after the fashion of Case, et al. (1991) and Case & Quigley (1991). With this method, we know that γ_n are "parameters to be estimated representing rate of change in the constant-quality house price appreciation index in the n^{th} time period." But this is precisely what the Case-Schiller single-family home price index represents (Case, et al., 1991, p. 292) (S&P Dow Jones Indices, 2020) (Shiller & Case, 1987). Thus, we will use such data as our home price index in the Case, et al. (1991) approach. The data is employed in the robustness check via equation (4). The result of such work is presented in table 2.

To the best of our knowledge, we are the first to attempt to use a partial "hybrid" approach for the examination of the possible relationship between marijuana on home prices (Burkhardt & Flyr, 2019) (Case, et al., 1991) (Cheng, et al., 2018) (Conklin, et al., 2020). This is an important check of our work. The home price index allows us to control for all changes in the value of a constant quality home over time. In our primary specifications of equations (1) and (3), this is achieved with time-fixed effects. But, by including the HPI, we can confirm the changes in home values over time are being properly accounted for with our time controls (Case, et al., 1991) (Diewert, 2013) (Haan & Diewert, 2013). Confirming the validity of the inclusion of time-fixed effects is even more critical when one considers their importance in accounting for autocorrelation. We discuss this more in appendix iii: cluster robust errors.

We also obtained three additional data sets for use with equation (3)'s robustness analysis. The motivation for such robustness exercises is detailed above in our methods section. Additionally, the results of such robustness analysis are presented in table 2. Note that all records used for robustness analysis covered the period of January 1st, 2014, to February 29th, 2020. The first of these robustness data sets hailed from the Bureau of Labor Statistics. Such records concerned the average wage in the Denver Metropolitan Statistical Area (MSA) (Bureau of Labor Statistics, 2022a). Our second source of robustness data originated from the Colorado State Demography Office. It pertains to the net migration rate for Denver County (Colorado State Demography Office, 2022). We chose the Colorado State demographers office because it represents "The most accurate source for such data" (Erffmeyer, 2021). Our treatment of this data is detailed in appendix v: monthly net migration data. The third and final set of robustness records concerns the total number of people employed in Denver County. This information comes from the Bureau of Labor Statistics Quarterly Census of Employment and Wages (Bureau of Labor Statistics, 2022b). To the best of our knowledge, we are the first to employ the economic characteristics of the average wage, net migration, and total employment, in the analysis of legalized marijuana's association with home values in Colorado (Burkhardt & Flyr, 2019) (Cheng, et al., 2018) (Conklin, et al., 2020). This represents an additional contribution of our research. The motivations and benefits of including robustness data have already been discussed in more detail in our methods section.

After obtaining and preparing the above eight distinct data sets, we merged them to create our primary dataset. Such records contain information on 46,490 home sales from January 1st, 2014, through February 29th, 2020, and the economic controls discussed above. However, our final analysis limits the number of home sales to 39,863 first-time home transactions. This is necessary because hedonic models assume all sales are separate. Thus the 6,627 repeat sales were not included in our analysis (Haan & Diewert, 2013). Still, 39,863 observations exceed the number of home sales employed by either Conklin, et al. (2020) or Burkhardt & Flyr (2019) in their analysis of Denver County. Thus, our data represent a rich pool of unique observations with which to conduct research.

Summary Statistics and Trends

We conclude our look at the data by considering the summary statistics presented in table 1. Additionally, graphs of the trends of our data are shown in figure 10. We have separated our primary dataset into first-time home sales, repeat sales, and all sales. We will only employ the first-time home sales data in our hedonic analysis (Haan & Diewert, 2013).

Table 1: Summary Statistics

	First Time Sales	Subsequent Sales	All Sales
Sale Price $	503,445.50 (349,741.00)	572,264.20 (338,125.40)	513,255.30 (348,935.90)
Living Area [Total square feet of]	1,620.49 (808.18)	1,595.76 (763.37)	1,616.96 (801.99)
Lot Size [Total Square feet of]	6,394.17 (2,781.03)	6,119.96 (2,366.48)	6,355.08 (2727.46)
Garage Area [Total Square feet of]	381.50 (205.27)	381.01 (195.84)	381.43 (203.95)
No. Fireplaces	0.7252 (0.7988)	0.7174 (0.7912)	0.7241 (0.7977)
No. Full Baths	2.16 (0.89)	2.23 (0.89)	2.17 (0.89)
No. Half Baths	0.40 (0.53)	0.40 (0.52)	0.40 (0.53)
No. Neighborhoods	259	249	259
No. Stories	1.40 (0.51)	1.41 (0.52)	1.40 (0.51)
Medicinal Revenue m-6 [In Millions of $]	14.95 (2.63)	13.9 (2.8)	14.8 (2.68)
Recreational Revenue m-6 [In Millions of $]	21.2 (10.85)	30.32 (6.47)	22.5 (10.82)
Net Migration	6,629.39 (3,156.76)	4,532.40 (2,073.78)	6,330.47 (3,113.68)
Average Wages	29.27 (1.51)	30.61 (1.67)	29.46 (1.60)
Persons Employed	1,507,304 (69,352.98)	1,571,446 (47,616.22)	1,516,448 (70,357.78)
Year Built	1960.36 (37.89)	1959.83 (38.20)	1960.28 (37.94)
Year Effectively Built	1966.31 (33.50)	1968.74 (32.22)	1966.65 (33.33)
Age Sold	56 (37.77)	58.06 (38.18)	56.29 (37.84)
Observations	39,863	6,627	46,490

Comparing the first-time home sales to subsequent observations, we see that the mean value is less for first-time sale homes. Interestingly, subsequently sold homes have diminished living area, smaller lots, and are slightly older than first-time sale homes. This is in keeping with findings that repeatedly sold homes are more likely to be starter homes that are quickly outgrown (Clap & Giaccotto, 1992). However, subsequently sold homes are superior in one regard: they have been renovated to such a degree that their effective age is two years younger than the mean of first-time home sales. Further, the age a home sold at indicates that the mean subsequent home sale occurred two years after the mean first-time sale. Thus, subsequent house sales benefitted from appreciating home values. Perhaps these two facts help explain why subsequent sales possess substantially increased mean sale prices.

However, the above observation fits with our proposed hypothesis. Consider that the mean recreational marijuana sold is much higher when subsequent home sales occur. Our data is, by definition, cross-sectional (Gujarati, et al., 2009). Thus, our means represent the statistical average value of a characteristic for an average home in our sample. For instance, looking at all our sales together, we see that the average home sold for $513,255.30. Similarly, such an average home would have a living area of 1,616.96 square feet. Finally, the mean amount of recreational marijuana generated six months before the sale of our average home would be $22.5 million.

Also, the mean of the year effectively built is greater than the actual year built for the entire sample. This points to the fact that the average home has been renovated. In fact, it has undergone renovations to the degree that it is effectively six years younger than the actual year built indicates. Thus, renovations appear to be impacting our sample, and the use of the year of effective construction is well-founded.

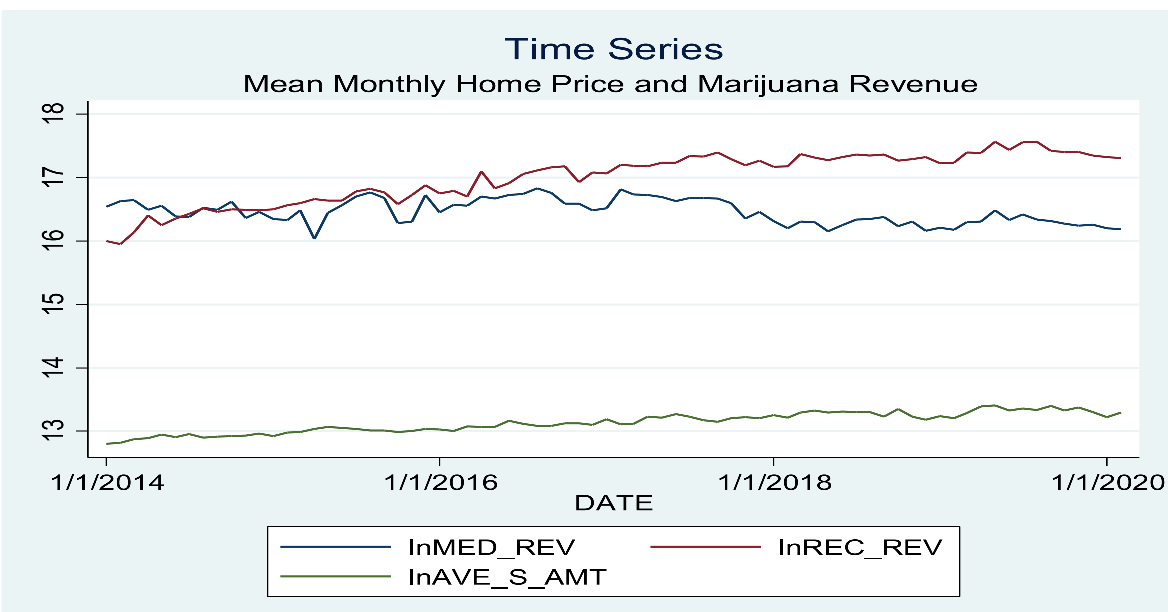

Figure 10. Mean Monthly Home Price and Marijuana Revenue

We focus next on the graphic presentation of the most relevant trends. Specifically, we shall consider the amount of medicinal and recreational marijuana revenue over time and the monthly mean sale price of a home. Recall our primary dataset is cross-sectional. However, we obtained a time series subset of data by considering a home's monthly mean sale price. Further, we have logged all our time series data in figure 10 to match our use of the natural log of marijuana revenue. This has the added benefit of making the comparisons between medicinal, recreational, and average home prices easier to observe.

Observe that as the amount of recreational marijuana revenue increased, the amount of medical marijuana sales decreased. This matches findings that consumers essentially see recreational marijuana as a substitute for medicinal marijuana. Thus, many that would have previously sought a medical marijuana card are instead opting to buy recreational marijuana, which has no such requirements (Orens, et al., 2018) (City of Denver, 2019) (Zhang, et al., 2017). Finally, the trend of average monthly home prices appears to be one of growth over time.

Results

This section deals with the estimates of equations (1), (3), and (4). Thus, consider table 2. Firstly, note that the chosen housing characteristics were included because they represent attributes required of any well-functioning hedonic model (Diewert, 2013). Additionally, most selected characteristics were utilized in previous research on marijuana and its relationship with home prices (Burkhardt & Flyr, 2019) (Conklin, et al., 2020) (Cheng, et al., 2018). However, we added controls for the primary type of material the home is constructed. Further, we included the additional housing characteristics of the garage area and the total number of fireplaces present. Such characteristics are commonly used in hedonic housing models (Weimer & Wolkoff, 2001).

Moving left to right. Column 1 represents the results obtained from the OLS estimation of equation (1). Columns 2, 3, and 4 contain the results of robustness checks carried out via equation (3). Finally, column 5 holds the results of our concluding robustness check obtained via the estimation of equation (4). The most noticeable aspect of the different equation estimates is their consistency regarding the coefficients' signs, magnitudes, and significances.

Examining the housing characteristics we see that regardless of the model used, all coefficient estimates remain virtually identical. Further, they are statistically significant at the 1% level throughout and possess the signs one would anticipate. That is, we would expect that as the living area, lot size, and garage area increase, so too does the home's value. Similarly, as the number of fireplaces, full and half baths grows, so does the home's price. Other hedonic research from Colorado finds the same for these characteristics (Bennet & Loomis, 2015) (Price, et al., 2010) (Mueller, et al., 2009).

Table 2: Results for Equations (1), (3), and (4)

$\ln(y_{imy})$ Variables	Hedonic: Eqn(1):	Hedonic: Eqn(3): NM	Hedonic: Eqn(3): NM,W	Hedonic: Eqn(3): W,NM,Emp	Hedonic: Eqn(4): W,NM
Intercept	4.0433*** (0.2479)	4.04*** (0.256)	5.8860*** (0.3946)	-0.5136 (5.7860)	-0.1407 (0.4082)
ln(Living Area)	0.3082*** (0.0063)	0.3082*** (0.0063)	0.3082*** (0.0063)	0.3081*** (0.0063)	0.3083*** (0.0064)
ln(Lot size)	0.1292*** (0.0038)	0.1292*** (0.0038)	0.1292*** (0.0038)	0.1292*** (0.0038)	0.1292*** (0.0038)
Garage Area	0.0001*** (0.00001)	0.0001*** (0.00001)	0.0001*** (0.00001)	0.0001*** (0.00001)	0.0001*** (0.00001)
Fireplaces	0.0306*** (0.0013)	0.0306*** (0.0013)	0.0305*** (0.0013)	0.0305*** (0.0013)	0.0308*** (0.0013)
Full Baths	0.1049*** (0.0015)	0.1049*** (0.0015)	0.1049*** (0.0015)	0.1049*** (0.0015)	0.1049*** (0.0015)
Half Baths	0.0574*** (0.0028)	0.0574*** (0.0028)	0.0574*** (0.0028)	0.0574*** (0.028)	0.0573*** (0.0028)
Stories	-0.0214*** (0.0035)	-0.0215*** (0.0035)	-0.0216*** (0.0035)	-0.0216*** (0.0035)	-0.0214*** (0.0034)
Year Effectively Built	0.0021*** (0.0001)	0.0021*** (0.0001)	0.0021*** (0.0001)	0.0021*** (0.0001)	0.0021*** (0.0001)
ln(MedRev6)	0.0189 (0.0127)	0.0189 (0.008)	0.012 (0.008)	0.012 (0.008)	-0.0153 (0.0122)
ln(RecRev6)	0.0022*** (0.0004)	0.0022*** (0.0004)	0.0021*** (0.0003)	0.0017*** (0.0004)	0.0025*** (0.0008)
ln(NetMig)	No	0.0001 (0.0091)	0.0030 (0.0054)	0.0038 (0.0056)	-0.0158** (0.0057)
ln(AveWage)	No	No	-0.5250*** (0.1124)	-0.466*** (0.1409)	-0.0282 (0.0678)
ln(Emp)	No	No	No	0.4762 (0.4238)	No
Material FE(13)	Yes	Yes	Yes	Yes	Yes
Neighborhood FE(258)	Yes	Yes	Yes	Yes	Yes
Month FE(11)	Yes	Yes	Yes	Yes	No
Year FE(6)	Yes	Yes	Yes	Yes	No
R^2	0.9300	0.9300	0.9301	0.9301	0.9225
AIC	-46,934.5	-46,934.5	-46,990.51	-46,986.38	-46,646.07
Observations	39,863	39,863	39,863	39,863	39,863

Stories have a negative effect, likely resulting from access and use issues for those with mobility limitations. Such a negative relationship is also consistent with previous hedonic literature (Neill, et al., 2007). The coefficient also makes sense when we consider the effective year a home was built. It tells us that a house becomes more valuable as the effective year of construction grows. Specifically, if we increase the effective year of construction for a home by one unit, there is an associated 0.21% increase in the home's value. That is, as the house becomes younger, it gains value. Conversely, as the home ages, it loses value. This is a common finding of hedonic home price models (Neill, et al., 2007) (Bennet & Loomis, 2015) (Price, et al., 2010). Recall that we carry out a robustness check supplanting the effective year of construction with age at the time of sale. We confirm the former to be a superior characteristic to account for age and renovations. See appendix vi: age at sale vs. effective year built.

At this juncture, we come to our variables of interest: six-month lagged marijuana revenue. Recall that we lagged by six periods because it resulted in the best-fitting model. Additionally, it matches well with the time it takes to locate and purchase a home with cash. Further, market price adjustment is not instantaneous (Ellie Mae, 2020) (Zillow, 2021c) (Zillow, 2021b) (Rosen, 1974) (Waugh, 1964). This is dealt with in more detail in appendix iv: ideal marijuana lag structure.

Continuing, consider the impact of medicinal marijuana on home prices. It appears to be statistically indistinguishable from zero. This is true for all equations estimated. One possibility for this insignificance is the distinct levels of legal scrutiny afforded medicinal vs. recreational marijuana. Recall that Colorado seed-to-sale laws and other regulations are laxer for recreational marijuana (Leynseele, 2021) (Stanojevic, 2020). Similarly, "There is no method of tracking consumers' purchases on the recreational side. In other words, there is no paper trail for recreational consumers. Medical consumers have a paper trail with their purchases since they must sign in with their medical card before shopping" (Council, 2019). Thus, there may be more opportunities to use recreational marijuana revenue for home purchases.

Additionally, the above seed-to-sale laws and benefits of vertical integration might incentivize purchasing homes for grow house purposes. For more on this idea, see Rasmussen (2022). This represents an area that bears further investigation. Additionally, recall that customers have been largely substituting medicinal marijuana for recreational (City of Denver, 2019) (Orens, et al., 2018). There is another viable reason for the lack of association between medicinal marijuana revenue and home prices: Medicinal marijuana revenue is at least partially bankable. While it is illegal to bank any marijuana funds, one credit union offers limited banking services to dispensaries. However, they are a small organization representing "only 1.5% of total credit union assets in Colorado" (Green

Wave Advisors LLC, 2017). Thus, they are very selective regarding the limited number of dispensaries they work with. Specifically, "preference was given to clients with an extensive background in medicinal marijuana" (Seefried, 2019b, p. 171). Such preference is likely due to medicinal dispensaries having existed longer and being much more monitored and regulated under Colorado's seed-to-sale laws (Stanojevic, 2020). Thus, given our hypothesized mechanism, it makes sense that little association might exist between medicinal marijuana revenue and home prices.

In stark contrast to medicinal marijuana, we can see that recreational marijuana has a highly statistically significant positive relationship with the natural logarithm of home prices. Additionally, the magnitude of such a relationship is roughly 0.0021. Thus, the coefficients indicate that a 10% increase in recreational marijuana is associated with an approximately 0.021% increase in home prices. The above is virtually unchanged throughout alternative model specifications. This implies that over our sample period, roughly 2% of growth in the mean value of a single-family home was related to the amount of recreational marijuana sold. This fits with Cheng, et al. (2018)'s finding that legalization of recreational marijuana was associated with a roughly 6% increase in home values. Their sample period ended in August 2015. But recall that 2015 was when Colorado seems to have started losing its first-mover advantage regarding the legalization of recreational marijuana (Zambiasi & Stillman, 2020). Add to this the aforementioned possibility that Cheng, et al. (2018) overestimated the impact of recreational legalization, and our findings make sense. Our results for recreational marijuana also match Navarro (2013)'s observation that there was a "positive and statistically significant" relationship between "cocaine exports" and "home prices" (Navarro, 2013, p. 69)

One final note regarding marijuana revenue's association with home prices: we conducted an additional regression analysis, where the total natural log of six-month lagged marijuana revenue was employed. In so doing, it was determined that the association between total marijuana revenue and home prices was virtually identical to that of recreational marijuana alone. This further validates the insignificance of medicinal marijuana on home prices.

Next, we address our robustness controls. The first noticeable feature of such controls is that in all specifications, save equation (4), the log of the average wage has a highly statistically significant negative relationship with home prices. Thus, as average wages increase, home values decrease, all else equal. At first glance, this is puzzling because "wages and prices tend to move together" (Knotek & Zaman, 2014, p. 4). However, "there is little evidence for cointegration of house prices and various fundamentals at the national level" (Gallin, 2006, p.

433). Average wage was the only control consistently associated with home prices. However, while the natural log of net migration was not itself significant, its inclusion improves the model's fit. This is evidenced by the highest AIC score belonging to the estimates of equation (3), presented in column 3. Additionally, the inclusion of the natural log of net migration has no discernable impact on the estimates of the other coefficients. Thus, by Gujarati, et al. (2009) we are justified in the retention of this control. However, the final control of the number of people employed in Denver County is insignificant. Additionally, the coefficients for the year controls are altered when such a control is included. More than this, the model fit has decreased. Finally, we consider the estimates of equation (4). We see that the Case, et al. (1991) approach yields virtually identical results, save for some of the robustness coefficients. However, this model fits the data substantially worse than previous specifications. Thus, we determine equation (3) of column 3 to be the optimal model choice.

But recall our discussion of alternative explanations for Cheng, et al. (2018) findings that a 6% increase in home values is associated with the legalization of recreational marijuana. The continued significant positive relationship between the amount of recreational marijuana revenue and home prices indicates that our results appear robust to such alternative explanations.

Turning to our controls, note that for the sake of legibility, the results are not presented in table 2. Merely their presence or absence is indicated. However, we report that in almost all cases, the primary material of home construction was significant at the 1% level. Similar controls have been used and found to have like results for previous hedonic literature (Price, et al., 2010). Additionally, 256 of our 258 neighborhoods have a statistically significant association with home values. This validates their inclusion and is in keeping with the findings of Oust, et al. (2020). Considering our inclusion of month controls and previous discussion of seasonality, note that all of them are statistically significant positive home price indicators. Additionally, the trend of monthly coefficients matches observed seasonal real estate patterns. That is, we saw a steady increase in home values up through the summer and fall before decreasing in November and then hitting a high in December (Griffin, 2018). Thus, our findings support the previously discussed research on the regional seasonality of prices, especially in the American West (Reichert, 1990) (Prasad & Richards, 2008) (Diewert, 2013). Finally, we come to our year dummies. They are all statistically significant and positively associated with increased home prices. Additionally, the trend of each year being progressively more impactful makes sense. However, note that month and year-fixed effects are only present in the estimations of equations (1) and (3).

Finally, the AIC measure strongly favors equation (3) with wage and net migration controls. This is because "The best model from the set of plausible models being considered is…the one with the smallest AIC value (the least information loss relative to the true model)" (Baguley, 2012, p. 402). These estimates are presented in column 3 of table 2 above. That model specification was also tied with columns 2 and 4 for the best R-squared statistics. All the models possessed remarkably high R-squared values (Gujarati, et al., 2009). Particularly, column 3's estimates of equation (3) explain roughly 93.01% of the observed variation in Denver County home prices between January 1st, 2014, and February 29th, 2020.

In summary, we have conducted numerous alternative model robustness checks, and all possess a nearly identical positive association between the amount of recreational marijuana revenue generated and the price of a single-family Denver home six months later.

Conclusion

We began this paper with a simple question: is there an association between the amount of marijuana revenue generated and home prices in Denver County, Colorado? We have seen that the answer is yes, at least for recreational marijuana. Specifically, we found that a 10% increase in recreational marijuana revenue today was associated with a 0.021% increase in Denver County home values six months later. This implies that from January 1st, 2014, to February 29th, 2020, roughly 2% of the growth in the mean value of a single-family home was associated with the amount of recreational marijuana sold. Such results have proven robust to every check, and alternative model specification we have reason to believe should be undertaken.

In the end, we have obtained a model that is exceptionally robust in its design and suitability for the research question posed (Haan & Diewert, 2013) (Diewert, 2013). Further, the independent variables of our model explain a very high degree of variation in the prices of homes sold in Denver County. Most importantly, our work adds to the findings of Cheng, et al. (2018), Burkhardt & Flyr (2019), and Conklin, et al. (2020). They all found a positive relationship between the legalization of marijuana and dispensaries on Colorado home prices. Yet, to the best of our knowledge, ours is the first research to investigate a mechanism by which home price increases might occur.

Further, the need for such an explanation was remarkably prescient. As Tyndall (2021) said, it is vital that "Work should…be undertaken to identify the underlying mechanisms that relate dispensaries to local housing demand" (Tyndall, 2021, p. 1118). We stepped into that void and put forward a process that can explain the observed marijuana-related impacts on Denver home prices (Snowden, 2020) (Seefried, 2019a). This mechanism has proved robust to all the alternative explanations we have reason to test it against. That is, we have failed to disprove the hypothesis that dispensaries are investing in Denver County homes.

Thus, our work here answers a relevant and timely question that has, to the best of our knowledge, hitherto gone uninvestigated. The insignificance of partially bankable medicinal marijuana, combined with the significance of recreational marijuana, is substantial evidence in favor of the idea that when banking access is lacking, dispensary owners might turn towards the real estate market. In fact, "as a result [of lacking banking access], the owners of marijuana businesses operate in a Wild West landscape" where home purchases may represent one of the few ways to protect or make bankable their vast inflows of cash (Seefried, 2019b, p. 165) (Seefried, 2019a).

As the first state to adopt legal recreational marijuana, Colorado has long served as the proverbial canary in the coal mine (Zambiasi & Stillman, 2020). Hence, the methods Colorado employed in the legalization of recreational marijuana have been imitated by many other late adopters (Leynseele, 2021) (Cheng, et al., 2018). Currently, 18 states and the District of Columbia have legalized marijuana for recreational purposes. Further, owing to the large amounts of tax revenue involved, more states are sure to follow (Garber-Paul & Bort, 2021) (Leung & Dutra, 2021) (Yakowicz, 2021).

As such, the associations and implications learned from Colorado's legalization of recreational marijuana could prove vital for policymakers to understand. Most importantly, consider what our results indicate regarding the legalization of recreational marijuana absent banking access for dispensaries and other auxiliary businesses. If dispensaries are Cheng, et al. (2018)'s "investors," then they are driving up housing demand and thus prices. Further, recall that Cheng, et al. (2018) found lower to middle-value homes most affected by such increased values. Therefore, together with Cheng, et al. (2018), our work implies that at the confluence of recreational marijuana legalization and lack of banking access exists a potential for shortages of affordable homes. But according to assistant professor and co-author of the book *Homelessness in America*, Gregg Colburn*,* America is already in the grips of an affordable housing "crisis." In fact, he lists "housing market dynamics" as the primary cause of affordable housing issues and homelessness in this nation. Particularly, "We have a gross undersupply of housing at all levels, but certainly of affordable housing. Failure to address that gap will, I think, guarantee that we will continue to struggle with this crisis in perpetuity" (Eckart, 2022). The above is not mere conjecture. The legalization of recreational marijuana has been associated with a decrease in the affordability of homes in Denver's "Green Mile" area (Voorde, et al., 2021). Unfortunately, poor and minority members of urban centers usually suffer the most from affordable housing issues (Richardson, et al., 2019) (Colburn, 2022). But in a cruel irony, such individuals bore the brunt of pre-marijuana decriminalization arrests, incarcerations, and subsequent impairments of potential future earnings (Hudak, 2020).

It is unlikely the green genie of recreational legalization will return to his lamp (Hudak, 2020). Instead, our research indicates a need for careful consideration of the SAFE banking act before the Senate banking committee. Such legislation would appear to have the potential to address issues currently plaguing a quasi-legal marijuana industry (117th Congress, 2022). Further, our research indicates that whoever Cheng, et al. (2018)'s investors are, the increase in home values associated with them appears to add fuel to the already rampant home affordability issues of Denver's most vulnerable communities.

In summary, we employed a tried-and-true econometric methodology with a novel dataset. In so doing, we fill a prescient gap in the existing literature. We find a positive association between the amount of recreational marijuana generated and home prices six months later. Further, approximately 2% of the observed growth in the mean value of Denver County single-family homes appears to be related to legalized recreational marijuana revenue generated. Such a finding is in keeping with Cheng, et al. (2018). More than this, we have expanded upon the existing literature by exploring a mechanism by which recreational marijuana and home prices could be related. Hence, our work here helps address a lack of research in a field that is "essential to the formation of responsible marijuana policy" (Hudak, 2020, p. 215). Thus, we wish this investigation offers a point of entry for future inquiry into this timely and intriguing arena of inquiry. For "there is not a single corner of the marijuana policy world that cannot be aided by additional analysis" (Hudak, 2020, p. 215).

CHAPTER 3-KNOW WHEN TO HOLD 'EM, KNOW WHEN TO FOLD'EM:

LEGALIZED MARIJUANA'S IMPACT ON DENVER, COLORADO HOME RESALE RATES

Introduction

The date of November 6th, 2012, was a historic one. It marked the passage of Amendment 64 and the reversal of almost 80 years of the illegality of recreational marijuana (Rasmussen, 2021). But such legality was only on the state level. Federally, marijuana remains an illegal substance (Hudak, 2020). Still, with Amendment 64, Colorado became the first state to legalize the sale of recreational marijuana (Conklin, et al., 2020). Since then, many other states have followed suit. Currently, 18 states and the district of Columbia possess legalized recreational marijuana. Further, 33 states have legalized medicinal marijuana (Garber-Paul & Bort, 2021) (Leung & Dutra, 2021).

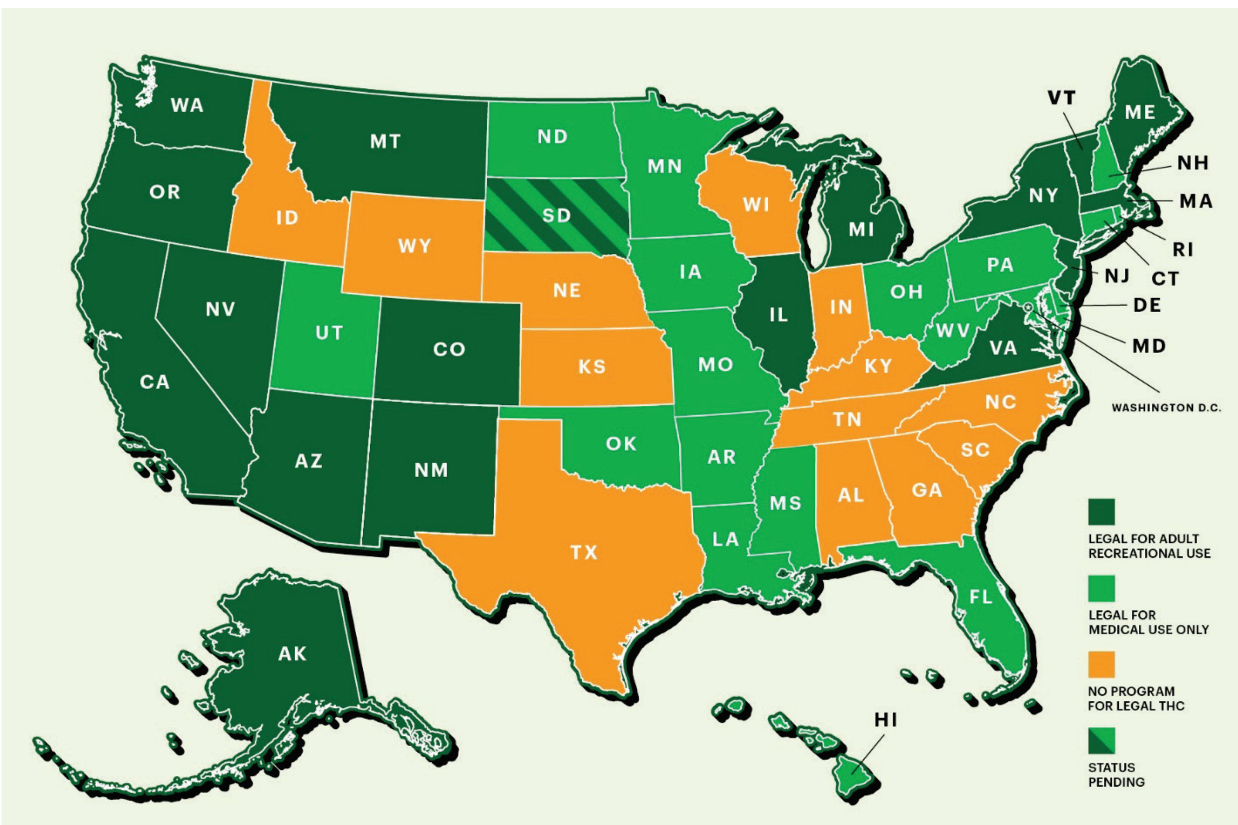

Figure 11. Legal Status of Marijuana by State (Garber-Paul & Bort, 2021)

Yet, as the number of legalized states increases, so does the market for legalized marijuana. National sales hit a record of $17.5 billion in 2020. Perhaps unsurprisingly, Colorado is one of the most significant drivers of such demand for recreational marijuana. The state represents one of the few “mature” markets of legalized marijuana. “In Colorado, where market penetration is greatest in the country, 48% of Coloradans imbibe [marijuana].” Putting that into perspective, alcohol has a market penetration of 60% (Yakowicz, 2021).

Literature Review

But with the above flourishing statewide legalization and revenue have come many questions about the implications of such legalization. One branch of inquiry regards the impacts of legalization on homes. Colorado is an ideal natural experiment for the legalization of recreational marijuana. This stems from its status as a “first mover” in the legalization of recreational marijuana (Zambiasi & Stillman, 2020, p. 2). There have been several papers finding a positive association between the legalization or presence of a legal dispensary and home prices in Colorado (Burkhardt & Flyr, 2019) (Cheng, et al., 2018) (Conklin, et al., 2020). Conklin, et al. (2020) and Burkhardt & Flyr (2019) examine the local impact of dispensaries on home prices. Both studies employ difference-in-difference methodologies. Conklin, et al. (2020) find an 8.4% increase in the prices of homes within a quarter mile of a dispensary that begins offering recreational marijuana. The researcher’s area of investigation was Denver County, Colorado.

Similarly, Burkhardt & Flyr (2019) investigates Denver County to see if the addition of a recreational dispensary increases surrounding home values. They discover that it does. Specifically, for homes located 0 to .25-miles from a new dispensary, there is an associated 7.7% increase in home values. When they consider a .25-to-.5-mile radius, the effect decreases to 4.7%. The third paper looking at the legalization of marijuana and homes in Colorado is by Cheng, et al. (2018). Such analysis is conducted via a difference-in-difference approach. In so doing, they determine a roughly 6% increase in metropolitan home prices associated with the legalization of recreational marijuana. Further, they employ a “linear probability model” to “find that the legalization makes it much more likely for listed properties to be sold, with the probability being driven up by 21 percentage points” (Cheng, et al., 2018, p. 1597). The authors postulate that such results may be the consequence of “ investors” who “ buy more properties, for either resale or rental purpose, in populous areas in order to obtain higher expected returns” (Cheng, et al., 2018, p. 1601).

Rasmussen (2021) builds upon Cheng, et al. (2018) by testing a hypothesized mechanism with the potential to explain the observed housing price increases. The author puts forward that Cheng, et al. (2018) are indeed correct in suspecting that real estate investment could be at the heart of increasing home prices. Specifically, the investment of dispensary owners. The author argues that this occurs because of dispensaries' lack of banking access. For "while Colorado has legalized the medical and recreational marijuana businesses and their transactions, the federal government has not. In fact, federal laws make it next to impossible for cannabis businesses to open checking or savings accounts…, or access lines of credit. Nor can they expect financial institutions to issue them a credit card or to process any credit card transactions involving their firm" (Seefried, 2019b, p. 165). Thus, "cannabis entrepreneurs meet all their obligations with cash" (Seefried, 2019b, p. 167). But cash on site has been shown to increase crime against dispensaries (Quinton, 2016). In fact, "No significant business transaction can be completed in this industry without factoring in the prospect of robbery" (Seefried, 2019b, p. 165). Yet, the research on crime and dispensaries in Colorado found dispensaries associated with decreased crime rates (Brinkman & Mok-Lamme, 2019) (Burkhardt & Goemans, 2019). Thus, Rasmussen (2021) postulates that dispensary owners are moving risky cash into real estate and are therefore Cheng, et al. (2018)'s "investors" buying up "properties, for either resale or rental purpose" (Cheng, et al., 2018, p. 1601). There are robust reasons dispensary owners might select real estate as the preferred investment of unbankable cash. As Rasmussen (2021) relates, "by purchasing local real estate, dispensary owners will have put their money into an investment that protects their wealth from crime, seizure, and inflation. Additionally, home value appreciation is stable and generally outperforms other assets over the long run" (Rasmussen, 2021, p. 23). For more details regarding the suitability of real estate for dispensary owner investment, please refer to Rasmussen (2021).

If dispensaries are Cheng, et al. (2018)'s investors, one would expect the amount of revenue the dispensary owners receive to incentivize home purchases and thus increase home values. Rasmussen (2021) deploys a hedonic modeling approach to investigate such a hypothesis. He finds a positive association between the amount of recreational marijuana revenue generated and the value of homes six months later. Specifically, for a 10% increase in the amount of recreational marijuana sold, there is an associated 0.021% increase in home values six months afterward. Further, approximately 2% of the rise in the mean value of Denver single-family homes is associated with increased recreational marijuana sales.

However, both Cheng, et al. (2018) and Rasmussen (2021) end their work with an unanswered question: What is the fate of such purchased homes? Are they being bought up "for either resale or rental" purposes? (Cheng, et al., 2018, p. 1601) (Rasmussen, 2021). Seefried (2019) contends homes might well be resold. This is because the money from the resale would be bankable. Thus, dispensaries buying homes could represent a means to launder their finances. This might be a tempting approach for dispensaries to access otherwise inaccessible banking services (Seefried, 2019a) (Seefried, 2016). There is strong evidence of real estate as a means of "money laundering." In one prominent example from the 1970s and '80s, as many as 1 in 5 Miami homes were purchased for "cocaine money laundering" purposes (Navarro, 2013, p. 64). Contrasting the above, the Denver Metro Drug Task Force indicates that homes purchased by dispensaries might be held. They argue that post-legalization of recreational marijuana, it became much harder to "bust" houses used for the illegal cultivation of marijuana. This is because it was now legal to possess and home-grow limited amounts of marijuana. Thus, establishing probable cause became a hurdle to clear (Snowden, 2020). Yet in Colorado, marijuana is "typically grown within "warehouses," not residential properties (Zhang, et al., 2017, p. 6). However, after the legalization of recreational marijuana, there was a rush by marijuana cultivators to purchase growing warehouses. This predictably drove up warehouse prices (Zhang, et al., 2017). Yet, as warehouses became scarce, growers may have looked towards the residential housing sector for hope. While utilization of homes for the commercial production of marijuana is illegal, products manufactured from such pants need not be. This is because Colorado seed-to-sale laws are not mandatory for recreational marijuana (Leynseele, 2021) (Stanojevic, 2020). Additionally, "There is no method of tracking consumers' purchases on the recreational side. In other words, there is no paper trail for recreational consumers" (Council, 2019). Thus, "gray market" marijuana growers seem to have the ability to avoid detection (Zhang, et al., 2017, p. 12) (Leynseele, 2021) (Stanojevic, 2020). More than this, dispensary owners unable to procure sufficient warehouse space have the incentive to avail themselves of illegal grow homes. This is because the IRS tax code does not allow dispensaries to write off expenses that other federally legal businesses can. Thus, cultivating your own product is more cost-effective than buying from a separate grower (Leynseele, 2021). Hence, a strong case exists regarding the possibility of dispensary owners purchasing and retaining homes for growing purposes. Now they may also wish to hold properties as legitimate rental units. Such an approach is an excellent way to protect your cash from inflation. Dispensary owners might also benefit from home value appreciation (Schaub, 2016).

We seek to resume the work of Cheng, et al. (2018) and Rasmussen (2021) via the determination of any association between the amount of marijuana revenue generated and home resale probabilities in Denver County. Consider that if there is a positive association between the resale probability of homes and marijuana revenue, it is evidence in favor of Seefried (2019a) and Navarro (2013). But if a negative relationship exists, it points toward homes being held by dispensary owners, as Snowden (2020) alludes to. Thus, we propose to employ logistic and probit models to determine if the amount of marijuana revenue generated is associated with Denver County single-family home resale probabilities.

Methodology

Primary Methods

Our question is simple: is the amount of marijuana revenue associated with the probability that a given home will resell? Such a question is binary. Either a given home was resold or not. Thus, our dependent variable is 1 if home *i* resold and 0 if it did not. Such a binary dependent variable did not exist in our primary dataset. Hence, we created it via existing data. This is detailed in appendix xi: creation of resold dependent variable.

Considering our dependent variable's binary nature, we can employ a logit or probit model. Research has been conducted to determine the superiority of one or the other of these models. However, "it is difficult to justify the choice of one…or another on theoretical grounds." In fact, "in most applications, the choice between these two seems not to make much difference" (Greene, 2012, p. 689). Yet, "historically, the main motivation for logit regression was that the logistic cumulative distribution function could be computed faster than the normal cumulative distribution function" (Stock & Watson, 2007, p. 395). Thus, "many researchers choose the logit model because of its comparative mathematical simplicity" (Gujarati, et al., 2009, p. 599). Hence, most existing literature on binary questions employs the logit model. Therefore, the logit model has the advantage of a more substantial library of research to draw on. But perhaps the most significant advantage of the logit model is that it is "one of few nonlinear models" that can achieve accurate coefficient estimates given the need for cluster-specific fixed effects (Cameron & Miller, 2015, p. 356).

Further, we know that our data likely suffers from spatial and serial autocorrelation (Rasmussen, 2021). Thus, by Cameron & Miller (2015), we need to include both cluster-specific fixed effects and cluster robust errors.

Therefore, we have chosen to follow in the footsteps of Pace & Zhu (2019) and Marios, et al. (2019) in their use of the logit model with methodological guidance from Gujarati, et al. (2009). However, we also employ a probit model as a robustness check of our results. Pace & Zhu (2019) utilized a logit model towards similar ends as ours: to determine those independent variables associated with home sale probabilities. In their case, the likelihood that a home would sell, and ours if it would resell. Marios, et al. (2019) looked at the residential location choice of senior citizens. Specifically, did they or did they not choose to locate in the Montreal metropolitan area (Marios, et al., 2019)? We have adopted and adapted the above authors' models to arrive at one suited to our research needs. First, consider a basic linear probability model. Gujarati, et al. (2009) present such a model in their consideration of the probability a family purchases a home. We have adapted it here for our purposes. Thus, consider equation (1) :

$$P_i = \alpha + \beta X_i \tag{1}$$

Where $P_i = E(Y_i|X_i)$ is the probability that property *i* is resold, given the independent variables believed to impact the probability home *i* resells, X_i. But it is well known that a linear probability model (LMP) is ill-suited for such a task. This is owing to its allowing P_i to take on values other than 0 or 1. Additionally, there are issues of non-normality and heteroscedasticity of the error term. Furthermore, unreliable R-squared values are an issue. “But even [when the above points are addressed]…the fundamental problem of with the LPM is that it is not logically a very attractive model because it assumes that $P_i = E(Y = 1|X)$ increases linearly with *X*, that is, the marginal or incremental effect of *X* remains constant throughout.” But this is “patently unrealistic” (Gujarati, et al., 2009, p. 581). Yet, Cheng, et al. (2018) use such a “linear probability model” to determine that “legalization [of recreational marijuana] makes it much more likely for listed properties to be sold, with the probability being driven up 21 percentage points” (Cheng, et al., 2018, p. 1597). However, we will consider an alternative to equation (1), and Cheng, et al. (2018)’s “linear probability model.” Such an approach is again adapted from Gujarati, et al. (2009)’s investigation of the probability of a family purchasing a home. Hence consider equation (2):

$$P_i = \frac{1}{1 + e^{-(\alpha+\beta X_i)}} = \frac{1}{1 + e^{-Z_i}} = \frac{e^Z}{1 + e^Z} \tag{2}$$

Where $Z_i = \alpha + \beta X_i$. Now P_i will range from 0 to 1, while $Z_i \in (-\infty, \infty)$. Finally, P_i no longer has a linear relationship to Z_i. But if P_i is the probability that home *i* resells, then $1 - P_i$ is the probability that property *i* fails to resell. Then by equation (2):

$$1 - P_i = \frac{1}{1 + e^{Z_i}}$$

Thus, if we want to know the odds ratio of home *i* reselling, we have the following:

$$\frac{P_i}{1 - P_i} = \frac{1 + e^{Z_i}}{(1 + e^{-Z_i})} = e^{Z_i} = e^{\alpha + \beta X_i} \rightarrow$$

$$ln\left(\frac{P_i}{1 - P_i}\right) = \alpha + \beta X_i \tag{3}$$

Where equation (3) is the natural log odds ratio of property *i* selling, given the amount of marijuana revenue associated with that sale. But notice that the righthand side of our equation is again linear. Thus, we have surmounted the shortcomings of a linear probability model, such as the one employed by Cheng, et al. (2018). Equation (3) is a basic version of our logit model. Understanding how we arrived at such a model allows us to consider our full model. In equation (4), we adopt a semi-log form of the logit model from (Marios, et al., 2019):

$$ln\left(\frac{P_{imy}}{1 - P_{imy}}\right) = \alpha + \sum_{j=1}^{J} \beta_j ln\ (QC_{jimy}) + \sum_{k=1}^{K} \delta_k QD_{kimy} + \sum_{e=1}^{E} \xi_{\ e} ExtWls_{ie}$$
$$+ \theta\ ln\big(MedRev_{(m-6)y}\big) + \phi\ ln(RecRev_{(m-6)y}) + \sum_{n=1}^{N} \eta_n NBHD_{in}$$
$$+ \sum_{m=1}^{M} \mu_m Month_{im} + \sum_{y=1}^{Y} \psi_y Year_{iy} + \epsilon_{imy} \tag{4}$$

Where, P_{imy} is the probability that property *i* will resell in month *m* of year *y*, and $1 - P_{imy}$ is the probability it will not sell in month *m* of year *y*, $ln\left(\frac{P_{imy}}{1-P_{imy}}\right)$ is the log odds ratio of property *i* reselling in month *m* of year *y*, QC_{jimy} is the quantity of home *i's j*th continuous characteristic in month *m* of year *y*, QD_{kimy} is the quantity of home *i's k*th discrete characteristic in month *m* of year *y*, $ExtWls_{ie}$ is a dummy variable assuming a value of 1 if home *i's* exterior walls were made of material *e* and 0 otherwise, $MedRev_{(m-6)y}$ is the total medicinal revenue generated in month (*m-6*) of year *y*, $RecRev_{(m-6)y}$ is the total recreational marijuana revenue generated in month (*m-6*) of year *y*, $NBHD_{in}$ is a neighborhood dummy variable, assuming a value of 1 if home *i* sold in neighborhood *n* and 0 otherwise, $Month_{im}$ is a month dummy, assuming a value of 1 if home *i* sold in month *m* and 0 otherwise, $Year_{iy}$ is a year dummy variable, assuming a value of 1 if home *i* sold in year *y* and 0 otherwise, and ϵ_{imy} is a heteroskedasticity, few cluster robust, cluster robust error term, for home i sold in month m of year y. Finally, α is the intercept, while $\beta, \delta, \xi, \theta, \phi, \eta, \rho, \mu, \psi$ are the model coefficients to be estimated.

Now consider the chosen independent variables. First, we logged our continuous characteristics. However, we have not logged the discrete characteristics. Such an approach is in keeping with Rasmussen (2021) and Case, et al. (1991). This allows us to compare percentage change increases in continuous independent variables and the log odds ratio. However, logging the discrete variables was impossible because of legitimate zero values for absent features. Another aspect to note is that all our housing characteristics were adopted from Conklin, et al. (2020), Cheng, et al. (2018), Burkhardt & Flyr (2019), and Rasmussen (2021). Such authors utilized either difference-in-difference or hedonic methods. However, the housing characteristics they employed are equally at home in a logit or probit regression of home resale probabilities (Pace & Zhu, 2019) (Gujarati, et al., 2009).

Now consider our primary variables of interest: marijuana revenue. We account for both medicinal and recreational revenue generated. Rasmussen (2021) found no significant association between medicinal marijuana and home prices. Thus, it is likely to be insignificant here as well. Yet medicinal and recreational marijuana are included to test our hypothesis of a relationship between the amount of marijuana revenue generated and the probability of resale. Specifically, if ϕ is statistically significant, it would indicate that home resale probability is associated with recreational marijuana revenue changes. Note that the amount of marijuana revenue has been lagged by six periods. Our work in appendix viii: ideal lag structure demonstrates this need. There, a six-period lag structure best explains the variation in home resale probabilities. This will be discussed further in our results section.

Next, consider the neighborhood cluster-specific fixed effects. These were incorporated "to account for locational neighborhood characteristics' impact on" resale rates (Rasmussen, 2021, p. 26). For instance, a neighborhood with high crime throughout the sample period could impact resale probabilities there. Additionally, neighborhood fixed effects help address spatial autocorrelation in the data (Cameron & Miller, 2015). Finally, Conklin, et al. (2020), Burkhardt & Flyr (2019), and Pace & Zhu (2019) all employ neighborhood fixed effects.

Month-fixed effects have been included to account for any possible seasonality. There has been a fair amount of research indicating seasonality as a factor in home purchases (Meese & Wallace, 1991) (Prasad & Richards, 2008) (Reichert, 1990). In fact, Rasmussen (2021) found seasonality associated with Denver County home prices. Intuitively, it makes sense that homes with specific characteristics might be more likely to sell and resell in certain months. For instance, homes with a fireplace might sell or resell better in winter months. When we compare the results of equation (4) with and without month dummies, we find that the former is superior. This can be seen in appendix x: exclusion of neighborhood and month controls. Another reason for including month-fixed effects is to account for serial autocorrelation (Cameron & Miller, 2015). Finally, year dummies have been added to help account for factors that change over time and might influence the likelihood of home resale. As with month-fixed effects, year dummies inclusion also goes a long way toward dealing with any serial autocorrelation in the data (Cameron & Miller, 2015). Furthermore, all the previous research on our topic employed year dummies (Burkhardt & Flyr, 2019) (Cheng, et al., 2018) (Conklin, et al., 2020) (Rasmussen, 2021). Lastly, the work of Pace & Zhu (2019) includes year-fixed effects in their logistic regression of home sale probabilities.

Finally, we include a heteroskedasticity, few cluster robust, cluster robust error term. This error term is one-way clustered on the quarterly date. Such an approach is based on the work of Cameron & Miller (2015). In conjunction with the cluster-specific fixed effects above, such an error term represents the most robust method of accounting for potential spatial and serial autocorrelations. Specifically, owing to the time series and spatial nature of some aspects of our cross-sectional data, such a method is advised (Cameron & Miller, 2015). We consider multiple error types in appendix vii: cluster robust errors. There we demonstrate the superiority of model fit and coefficient accuracy with our chosen error term. For a more detailed discussion regarding the need for such errors, please see appendix iii: cluster robust errors of Rasmussen (2021) and the work of Cameron & Miller (2015).

Robustness Checks

Our work builds on both that of Cheng, et al. (2018) and Rasmussen (2021). Rasmussen (2021) found a highly significant positive association between the amount of marijuana revenue generated and home values in Denver County. The author hypothesized that such an association existed because dispensary owners might be investing in local real estate. However, several prominent alternative explanations existed for the discovered relationship. Thus Rasmussen (2021) undertook a series of robustness checks to help account for such alternatives. Now, we examine a related hypothesis to Rasmussen (2021). Additionally, our data is fundamentally the same as Rasmussen (2021). Thus, we would be well advised to conduct similar robustness checks to those of Rasmussen (2021).

Firstly, the legalization of recreational marijuana might represent an amenity to workers. Thus, people would migrate to Denver County to access the amenity. This is what Zambiasi & Stillman (2020) concluded in their research. They found legalization of marijuana led to a 3.2% increase in the population of Colorado by 2015. They determined that the legalization of marijuana was viewed as an amenity and thus initially drew immigrants to the state (Zambiasi & Stillman, 2020). But then altered net migration patterns could be what drives any change in resale rates. Specifically, those that view legalized recreational marijuana as an amenity might have different ownership periods than other homeowners. That is, they might purchase homes for longer or shorter durations. Now consider figure 12, reproduced from Rasmussen (2021).

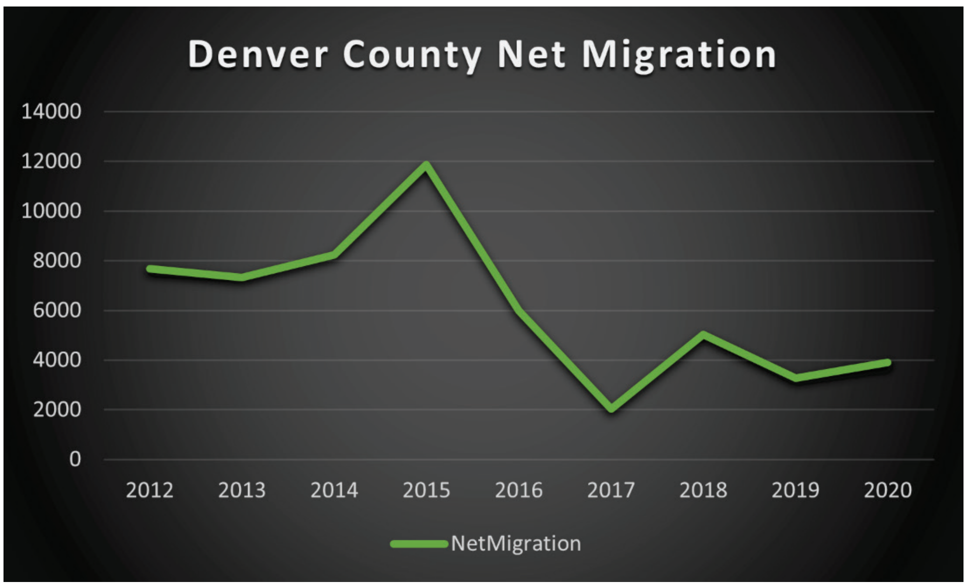

Figure 12. Denver County Net Migration Data From (State Demography Office, 2021)

Apparently, for the year recreational marijuana was legalized, net migration to Denver County increased. Such a trend aligns with the research of Zambiasi & Stillman (2020). Yet, as the number of states with legalized recreational marijuana grew, Colorado lost its "first mover state" status. This lines up with the considerable post-2015 net migration decrease (Zambiasi & Stillman, 2020, p. 678). Not coincidentally, Washington state began the sale of legalized recreational marijuana in July 2014 (Hudak, 2020).

Thus, "it is dubious if marijuana-induced population growth could exert constant positive impacts…" (Rasmussen, 2021, p. 30). In our case, it is unlikely that the above net migration pattern would exert a continuous positive or negative impact on the probability of home resale. However, it is best to account for such potential. Thus, we include such information in our primary regression results of table 4.

Think on the words of Rasmussen (2021) regarding our next robustness check:

> Consider the work of Zambiasi & Stillman (2020). They claim that "potential migrants view legalized marijuana as a positive amenity," at least until the end of 2015 (Zambiasi & Stillman, 2020, p. 11). However, they are silent on the views of firms regarding the legalization of marijuana. Yet to determine the general equilibrium outcome of the Roback model they cite, one needs to understand the firms' view of the amenity. If an amenity is "unproductive" for firms, we should see a decrease in the equilibrium wage paid to Denver workers (Roback, 1982). "Unproductive" amenities are ones that increase firms' costs, such as "clean air because firms must spend resources to use nonpolluting technology" (Roback, 1982, p. 1261). Thus, consider that "Costs[for firms] such as identifying, hiring, and retaining capable employees while maintaining a drug free environment are increasing in time and money as more people are able to use marijuana legally." Further, "Other potential costs relate to lost productivity, increased absenteeism, workplace accidents, and litigation costs. Research has shown that marijuana use increases the costs related to all of these…as more people are permitted to legally use marijuana" (Elliott, et al., 2019, p. 21). Thus, marijuana legalization most closely fits Roback's definition of an "unproductive amenity" for firms (Roback, 1982, p. 1260).
>
> But given the above, if "potential migrants view legalized marijuana as a positive amenity," then Roback (1982) implies that "wages should be lower, while the change in rent is uncertain" (Zambiasi & Stillman, 2020, p. 11) (Roback, 1982, p. 1262). Thus, we must look at the trends of average wages in Denver County, not rents, to determine the possibility of legalized recreational marijuana being a positive amenity for workers. Note that we employ average hourly earnings data because "this measure is perhaps the closest of our measures to the concept of wages" (Knotek & Zaman, 2014, p. 1).

We too must consider wages together with net migration in any meaningful determination of the amenity status of legalized recreational marijuana. Therefore, study figure 13, reproduced from Rasmussen (2021).

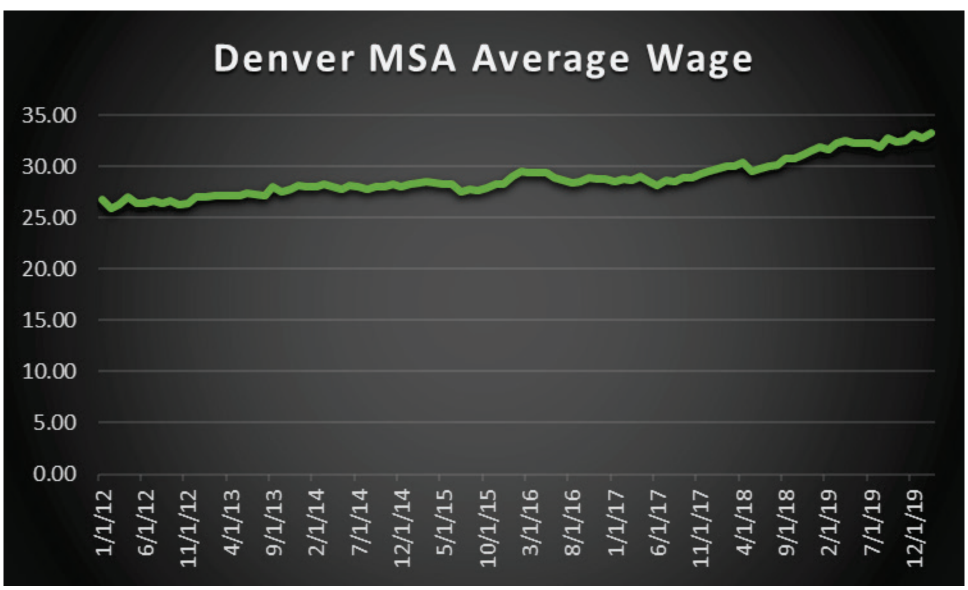

Figure 13. Denver MSA Average Wage Data From (Bureau of Labor Statistics, 2022a)

Overall, the trend is one of increasing average wages. This does square up with legalized recreational marijuana as a Roback amenity for workers. If legalized recreational was such an amenity, we should have seen decreased average wages. However, “there was a slight decrease in the average wage from the end of December 2013 through most of 2015” (Rasmussen, 2021, p. 31). Together with the trend of net migration, which initially increased after the legalization of recreational marijuana, we have a picture of legalized recreational marijuana that may well have initially represented an amenity to workers. However, this does not appear to be valid throughout the sample period. This is perhaps why Zambiasi & Stillman (2020) restrict their investigation of the amenity status of legalized recreational marijuana to 2015. Yet, “it could be that while the nominal average wage has increased, the real income workers received has decreased after the legalization of recreational marijuana” (Rasmussen, 2021, p. 31). Thus, we reproduce the following figure from Rasmussen (2021).

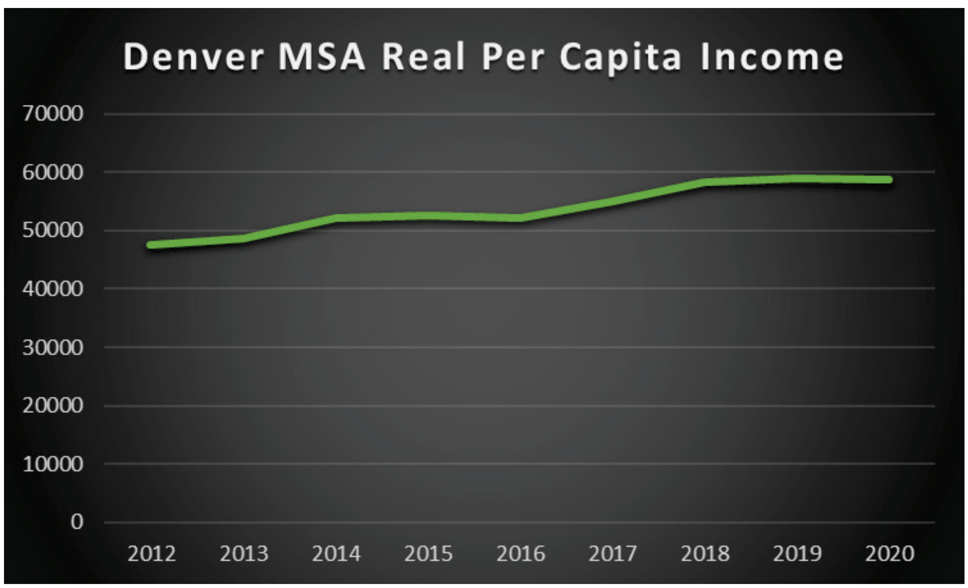

Figure 14. Denver MSA Real Per Capita Income Data From (Bureau of Economic Analysis, 2022)

This figure provides even less support for the idea of legalized recreational marijuana revenue representing an amenity to workers. Thus, “there seems scant evidence to support the idea that wages decreased over the time in question. In fact, both nominal wages and real income per capita increased. But again, we should see reduced wages if legalized marijuana represents a positive amenity for workers.” More than this, “If the legalization of marijuana did represent a positive amenity, Roback (1982) indicates that we should see both increasing net migration and decreasing wages. But beyond 2015, we see the very opposite of this: Increasing wages and decreasing net migration” (Rasmussen, 2021, p. 32)

However, we will include records on the average wage in the Denver MSA. This is recommendable because other reasons for increased wages may exist during our sample period. Further, any cause for altered wages might impact a home's resale probability. The result of such an addition is presented in table 4.

Our last robustness records involve the number of people employed in Denver County. The reason for such an addition is that the legalization of marijuana has "created jobs" for Denver County residents (Hudak, 2020, p. 203). Thus, even if net migration has declined, it could be that the number of employed native Denverites has increased as a result of the legalization of recreational marijuana. Thus, a change in home resale probabilities might result from more jobs and not dispensaries altered home selling patterns. To account for such a possibility, we include employment data in our final analysis, presented in table 4. Hence, consider figure 15, reproduced from Rasmussen (2021).

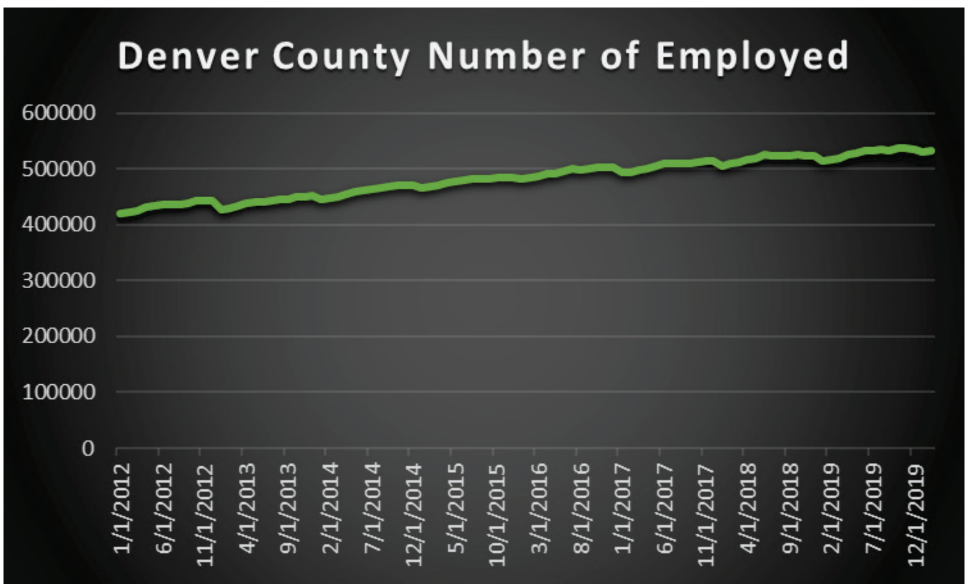

Figure 15. Denver County Employment Data From (Bureau of Labor Statistics, 2022b)

It is important to note that there is no drastic increase in the number of individuals employed pre and post-legalization of recreational marijuana. If legalization were associated with substantial growth in the number of those employed, we would expect to see a dramatic increase. Instead, we see a slow but steady trend of increasing numbers of employed Denverites.

Now let us consider equation (5). It contains the additional terms to account for the above-discussed robustness concerns.

$$ln\left(\frac{P_{imy}}{1-P_{imy}}\right) = \alpha + \sum_{j=1}^{J} \beta_j ln\ (QC_{jimy}) + \sum_{k=1}^{K} \delta_k QD_{kimy} + \sum_{e=1}^{E} \xi\ _e ExtWls_{ie}$$
$$+ \theta\ ln\big(MedRev_{(m-6)y}\big) + \phi\ ln(RecRev_{(m-6)y}) + \lambda \ln\big(NetMig_{my}\big)$$
$$+ \kappa \ln\big(AveWage_{my}\big) + \gamma \ln\ (Emp_{my}) + \sum_{n=1}^{N} \eta_n NBHD_{in} + \sum_{m=1}^{M} \mu_m Month_{im}$$
$$+ \sum_{y=1}^{Y} \psi_y Year_{iy} + \epsilon_{imy} \tag{5}$$

Where $\ln\big(NetMig_{my}\big)$ represents the natural log of net migration occurring in month *m* of year *y,* $\ln\big(AveWage_{my}\big)$ is the natural log of the average wage in month *m* of year *y*, and $\ln\ (Emp_{my})$ expresses the natural log of the number of employed individuals in Denver County in month *m* of year *y*.

However, recall that we follow Pace & Zhu (2019) by considering a probit model as a final robustness test of our primary estimates of equations (4) and (5). Such a probit model is based on the theoretical foundations of Pace & Zhu (2019) and Gujarati, et al. (2009). Thus, consider equation (6):

$$I_i = \beta_0 + \beta_1 X_i \tag{6}$$

Where, I_i, is the latent variable, such that the greater is I_i the more likely home *i* is to resell, and X_i are the independent variables thought to influence the probability that home *i* resells. As with the logit model, we have a binary outcome RESOLD equal to 1 if home *i* resold and 0 otherwise. RESOLD is discussed in more detail in appendix xi: creation of resold dependent variable. Yet the probability of I_i^* being less than I_i can be determined via the standardized normal cumulative distribution function. Hence equation (7):

$$P_i = P(RESOLD = 1|X) = P(I_i^* \leq I_I) = P(Z_i \leq \beta_0 + \beta_1 X_i) = F(\beta_0 + \beta X_i) \tag{7}$$

Where $P(RESOLD = 1|X)$ represents the probability of a home reselling, given the values of *X*, and Z_i is known as "the standard normal variable, i.e., $Z \sim N(0, \sigma^2)$" and *F* represents the normal cumulative distribution function (Gujarati, et al., 2009, p. 595). But we know by Gujarati, et al. (2009) that given equation (7), we can determine the relationship between I_i and our explanatory variables X_i by employing "the inverse" of equation (7) (Gujarati, et al., 2009, p. 595). Thus, we have equation (8):

$$I_i = F^{-1}(I_i) = F^{-1}(P_I) = \beta_0 + \beta_1 X_i \tag{8}$$

Adapting the above for our purposes, we arrive at equation (9).

$$I_i = \alpha + \sum_{j=1}^{J} \beta_j ln\,(QC_{jimy}) + \sum_{k=1}^{K} \delta_k QD_{kimy} + \sum_{e=1}^{E} \xi_{\ e} ExtWls_{ie} + \theta\, ln\big(MedRev_{(m-6)y}\big)$$

$$+ \phi\, ln(RecRev_{(m-6)y}) + \lambda \ln\big(NetMig_{my}\big) + \kappa \ln\big(AveWage_{my}\big) + \sum_{n=1}^{N} \eta_n NBHD_{in}$$

$$+ \sum_{m=1}^{M} \mu_m Month_{im} + \sum_{y=1}^{Y} \psi_y Year_{iy} + \epsilon_{imy} \tag{9}$$

Equation (9) is our final robustness check of the best-fitting primary logit modeling strategy we employ via equations (4) and (5). Recall that theoretically, there is little to recommend the probit over the logit model (Greene, 2012). However, we selected the logit model as our primary specification because it can adequately estimate model coefficients when cluster-specific fixed effects are needed. Thus, comparing the signs and significances of our probit estimates can be a final check of the robustness of our logit results. Such a check is presented in table 4.

Data

To begin with, let it be noted that we share all our data with Rasmussen (2021). Thus, one is referred to such work for more details regarding the following data. Here we employ the same primary dataset constructed and utilized by Rasmussen (2021).

Our first data regards single-family residential home sales and characteristics. The records concern all single-family homes sold in Denver County from January 1st, 2014, to February 29th, 2020. Note that the periodicity of this data is monthly. This data was obtained from the Denver County Assessors Office. Compared to the Rasmussen (2021) housing data, we had to exclude ten neighborhoods and the 85 home sales they contain. Such sales were omitted because they perfectly predicted failure to resell. Those neighborhoods had no home resales and thus had to be removed from our sample.

The second dataset contains the 2.9% medicinal and 2.9% to 15% recreational marijuana tax revenue records. The periodicity of the data is also monthly (Colorado Department of Revenue, 2021). The above records allowed for the determination of total monthly medicinal and recreational marijuana revenue from January 1st, 2014, to February 29th, 2020. To the best of our knowledge, Rasmussen (2021) and ourselves are the only ones to employ the above data in answering questions surrounding marijuana legalization and the Denver Housing market.

Now consider the reasons behind the use of the above data sources. First, we follow in the footsteps of Rasmussen (2021) in considering the sample period of January 1st, 2014, to February 29th, 2020. This time frame was primarily chosen because it excluded the Great Recessions and shocks of Covid 19. Both events carried with them unusual demand conditions. Thus, they are best avoided if one wishes for a sample representative of the Denver Housing market (Rasmussen, 2021). Additionally, recreational marijuana was first sold on January 1st, 2014 (Colorado Department of Revenue, 2019). We have selected a monthly periodicity for our data. Had we considered quarterly or yearly home sales, our marijuana revenue would have been aggregated, and its more granular impacts obscured.

Regarding our area of consideration, we choose to focus on Denver County. Here we follow the guidance of Rasmussen (2021), who:

> Investigate Denver County for several reasons. Firstly, Cheng, et al. (2018) found metropolitan areas were driving the trend of marijuana legalization and its associated "6% increase in home values" (Cheng, et al., 2018, p. 1). Thus, our county of analysis needed to be a metropolitan one. Secondly, we wanted to focus on one county. "Economists have long recognized that housing markets are geographically localized; thus, housing price indices are typically estimated for a geographic area no larger than the county or metropolitan area…." (Case, et al., 1991, p. 287) Hence, by considering one sub-state level area of analysis, we follow in the footsteps of a host of previous home price modeling literature, including Case & Quigley (1991), Case, et al. (1991), Quigley (1995), Hill, et al. (1997), Case, et al. (2006), Conklin, et al. (2020), Burkhardt & Flyr (2019), and Oust, et al. (2020). Thirdly, Denver County possesses sufficient housing characteristics for effective hedonic analysis. In fact, Denver has some of the most robust housing data in the nation (Erffmeyer, 2021). Fourthly, while "many believe [Denver County] to be drastically different from the rest of Colorado," Cheng, et al. (2018) showed that it is representative of all metropolitan areas of Colorado (Cheng, et al., 2018, p. 22).

Hence, we too "feel confident that…Denver County is…valid and generally representative of the overarching trends of legalization of marijuana", as they pertain to homes and home resale rates in metropolitan areas of Colorado (Rasmussen, 2021, p. 36).

Our unit of investigation is the single-family home. This too was done per the work of Rasmussen (2021). We utilize single-family homes because considering all residential home styles in the same analysis is to be avoided (Case, et al., 1991). Different housing characteristics impact different home types in unique ways. Thus, grouping unique home styles in one analysis is a subpar tact (Haan & Diewert, 2013) (Erffmeyer, 2021). For example, "the view provided by a condominium substantially affects its value. Suppose one condominium is on the second floor and thus provides a superior view of the Rocky Mountains. Consider an identical condominium situated on the first level of the same building. The condominium with the better view will be more valuable, all else equal. Yet single-family homes typically have a similar number of stories. Thus, the view is likely to be comparable in adjacent properties" (Rasmussen, 2021, p. 37). Denver County Assessors adhere to the above guidelines, and so shall we (Erffmeyer, 2021). Additionally, single-family residences "comprise the majority of residential properties sold in Denver County," between January 2014 through February 2020 (Rasmussen, 2021, p. 47). Finally, single-family homes are the most common home type examined in previous literature (Conklin, et al., 2020) (Dorsey, et al., 2010) (Shiller & Case, 1987) (Berry & Bednarz, 1975) (Clap & Giaccotto, 1992) (Case, et al., 1991) (Case & Quigley, 1991).

We also employ data pertaining to net migration, average wages, and the total number of employed Denver citizens. All such data covers January 1st, 2014, to February 29th, 2020. We employ this data for the same reasons Rasmussen (2021) does, to test our findings' robustness. The motivation for including this data is discussed at greater length in the previous methods section.

The first of our robustness data relates to the net migration rates of Denver County. This data is obtained from the Colorado State Demography Office (Colorado State Demography Office, 2022). The original periodicity of such information is annual. A cubic spline methodology is employed to estimate the monthly values of net migration. Such a method is taken up at greater length in appendix v: monthly net migration data of Rasmussen (2021). Ultimately, this data provides monthly estimates of net migration for Denver County. The second robustness data comes from The Bureau of Labor Statistics. These records relate to the average wage in the Denver Metropolitan Statistical Area (MSA) (Bureau of Labor Statistics, 2022a). Such data has monthly periodicity. Our final records pertain to the number of Denver citizens employed. This data was also monthly in periodicity and gathered from The Bureau of Labor Statistics, Quarterly Census of Employment and Wages (Bureau of Labor Statistics, 2022b).

We end this section by considering the summary statistics presented in table 3. The average Denver County home was 56 years old when it sold for $525,672.70. Such a home had a total living area of 1,629 square feet, a lot size of 6,379 square feet, two full bathrooms, less than one entire half bath, 1.5 stories, and was built in 1961. Additionally, it was remodeled to an effective age of 1967. Lastly, the mean monthly medical marijuana generated six months before the average home resale was 14.66 million. For recreational marijuana, that amount was roughly 23.87 million.

Table 3: Summary Statistics

	Home Sales
Sale Price $	525,672.70 (349,866.30)
Living Area [Total square feet of]	1,629.12 (808.18)
Lot Size [Total Square feet of]	6,378.64 (2,585.04)
Garage Area [Total Square feet of]	384.30 (204.34)
No. Fireplaces	0.73 (0 .80)
No. Full Baths	2.19 (0 .89)
No. Half Baths	0 .40 (0.53)
No. Neighborhoods	249
No. Stories	1.40 (0.51)
Medicinal Revenue m-6 [In Millions of $]	14.66 (2.72)
Recreational Revenue m-6 [In Millions of $]	23.87 (10.44)
Net Migration	6,055.78 (3,073.72)
Average Wages	29.63 (1.65)
Persons Employed	501,909 (23,829)
Year Built	1960.53 (37.94)
Year Effectively Built	1967.06 (33.16)
Age Sold	56.27 (37.85)
Observations	39,778

Results

This section is concerned with the estimations obtained with equations (4), (5), and (9) in the previous section. Thus, consider table 4. Moving left to right, column 1 contains equation (4) estimates and represents our base logit model. Column 2 holds the results of equation (5), where we add the robustness check of the natural log of net migration. The idea is to account for the possibility that the legalization of marijuana altered migration patterns in Denver County. When this is done, virtually all the results of our logit model remain unchanged. This speaks to the robustness of our results in the face of such a competing mechanism. Further, the addition of net migration data seems to leave the fit of our model unaltered. Such an inclusion is statistically significant at the 10%. Additionally, it does not cause any alterations of other variables or multicollinearity issues. Thus, we are justified in retaining net migration information in our subsequent regressions.

Table 4: Results for Equations (4), (5), and (9)

$ln\left(\frac{P_i}{1-P_i}\right), I_i$ Variables	Logit: Eqn(4):	Logit: Eqn(5): NM	Logit: Eqn(5): NM,W	Logit: Eqn(5): NM,W,Emp	Probit: Eqn(9): NM,W
Intercept	-3.0836 (5.6477)	-9.0683 (6.3519)	26.8896 (16.9757)	52.933 (256.5861)	13.4259 (8.8721)
ln(Living Area)	-0.2341** (0.0913)	-0.2355** (0.0914)	-0.2362** (0.0918)	-0.2361** (0.0918)	-0.128** (0.0506)
ln(Lot size)	-0.4282*** (0.0848)	-0.4287*** (0.0849)	-0.4296*** (0.0846)	-0.4296*** (0.0846)	-0.2394*** (0.0466)
Garage Area	0.00001 (0.0001)	0.00001 (0.0001)	0.00001 (0.0001)	0.00001 (0.0001)	0.00001 (0.0001)
Fireplaces	-0.013 (0.025)	-0.0127 (0.0250)	-0.0136 (0.0251)	-0.0137 (0.0251)	-0.01 (0.0145)
Full Baths	0.1481*** (0.031)	0.1484*** (0.0309)	0.1489*** (0.0309)	0.1489*** (0.0309)	0.086*** (0.0164)
Half Baths	0.0367 (0.0405)	0.0372 (0.0405)	0.0377 (0.0403)	0.0377 (0.0403)	0.0196 (0.0227)
Stories	0.020 (0.0713)	0.0206 (0.0713)	0.0186 (0.0715)	0.0185 (0.0715)	0.0102 (0.0402)
Year Effectively Built	0.002*** (0.0007)	0.002*** (0.0007)	0.0019*** (0.0007)	0.0019*** (0.0007)	0.001*** (0.0004)
ln(MedRev6)	-0.3489 (0.3115)	-0.0948 (0.3329)	-0.2068 (0.2915)	-0.2067 (0.2894)	-0.0838 (0.1599)
ln(RecRev6)	0.3337*** (0.078)	0.3315*** (0.079)	0.3562*** (0.1204)	0.3558*** (0.1179)	0.1126*** (0.0269)
ln(NetMig)	No	0.2027* (0.1127)	0.3737*** (0.1181)	0.3673** (0.1537)	0.1734*** (0.0645)
ln(AveWage)	No	No	-10.8628** (5.3451)	-11.067** (5.5115)	-5.1883* (2.7024)
ln(Emp)	No	No	No	-1.937 (19.1262)	No
Material FE(13)	Yes	Yes	Yes	Yes	Yes
Neighborhood FE(258)	Yes	Yes	Yes	Yes	Yes
Month FE(11)	Yes	Yes	Yes	Yes	Yes
Year FE(6)	Yes	Yes	Yes	Yes	Yes
AIC	29,119.61	29,114.74	29082.07	29,086.03	29100.38
Observations	39,778	39,778	39,778	39,778	39,778

Hence, consider column 3 and its results of equation (5). Such estimates include the natural log of net migration and average wages for Denver. Just as with the inclusion of net migration, average wages have increased the goodness of fit of our model. This is evidenced by the lowest AIC thus far. In fact, this model exhibits the lowest

AIC of all models considered. Furthermore, nearly all our coefficients are effectively identical to the two previous models. The exception is the significance of the natural log of net migration. Once average wages have been included in the model, net migration is now significant at the 1% level. Finally, the inclusion of the natural log of average wages indicates that our results are robust to changing wages. This is witnessed via our virtually identical association between the log odds ratio of home resale and the amount of marijuana revenue six months past.

Now we come to column 4 and its equation (5) estimates. Here all the robustness checks we have reason to consider are included. It appears that our coefficient estimates, and significances, are unaltered from previous models. However, if we had reported the coefficients of the year-fixed effects, it would be plain that a change had occurred. Specifically, all previous regressions exhibited positive statistically significant impacts on home resale. The exception was the consistent insignificance of 2015. However, once the natural log of individuals employed in Denver County was added to the model, all such year-fixed effects became insignificant. Further, we found troublingly high collinearity between the natural log of individuals employed and both year-fixed effects and the natural log of average wages. Finally, the number of employed individuals is insignificant. Thus, all the above indicates that this variable is ill-suited to our model (Gujarati, et al., 2009). However, by considering such an inclusion, we addressed the possibility that a change in the number of Denverites employed impacted resale probabilities. Yet, all our estimates of housing characteristics and marijuana revenue are unaffected by the addition of the natural log of those employed in Denver County. This speaks to the robustness of our results in the face of such concerns.

The final column contains the probit model estimates of equation (9). Recall that we follow Pace & Zhu (2019) in consideration of both a logit and probit model analysis of home resale likelihoods. Comparing columns 3 and 5, we see they agree on the impacts of all the variables considered. This is true both of the significance and direction of the coefficients. Specifically, both models indicate that a rise in the amount of recreational marijuana is associated with an increase in the chance that a home will resell six months later. However, as logit and probit models employ the cumulative logistic distribution function and standard normal cumulative distribution function respectively, we cannot directly compare coefficients. Still, such a robustness check speaks to the strength of our results across different models (Gujarati, et al., 2009).

Having considered the stability of our results across alternative specifications, we turn to what such results indicate. Firstly, recall that all the housing characteristics included are based on existing literature (Burkhardt & Flyr, 2019) (Cheng, et al., 2018) (Conklin, et al., 2020) (Rasmussen, 2021). Additionally, almost all of such characteristics have been employed by the authors upon whose shoulders our logistic model stands (Marios, et al., 2019) (Pace & Zhu, 2019) (Ondrich, et al., 2003). In table 4, the first thing of note is that as the size of the home and the lot it occupies increase, there is a statistically significant decrease in the resale rate. This fits with the findings of Pace and Zhu (2019). The number of full bathrooms positively affects the chance of resale. However, half bathroom's association with resale was statistically indistinguishable from zero. Stories, garage area, and the number of fireplaces were also insignificant. However, the home's effective age was positive and significant at the 1%. This indicates that younger homes are more likely to resell. Or at least renovated homes are more likely to resell. Pace and Zhu (2019) find the inverse measure of age to be similarly significant. Rasmussen (2021) found all the above characteristics to be statistically significant indicators of home value. However, as we have seen here, it is generally true that many of the characteristics associated with changing home values are not related to the chance a home will resell (Bennet & Loomis, 2015) (Price, et al., 2010) (Mueller, et al., 2009) (Neill, et al., 2007) (Pace & Zhu, 2019). Given the apparent lack of research on housing characteristics' impact on resale changes, our analysis is of value to this field (Pace & Zhu, 2019).

Regarding our controls, they have mixed results. Most neighborhoods do not have statistically significant associations with resale rates. Only 85 out of 248 were statistically significant. In Rasmussen (2021), neighborhood controls were almost all statistically significant. So once again, we see that being associated with increased home prices does not guarantee being associated with resale chances. However, including neighborhood controls is still vital (Pace & Zhu, 2019). In fact, we conducted yet another robustness check via the exclusion of neighborhood controls. When neighborhood fixed effects were removed, the model fit was substantially decreased. See appendix x: exclusion of neighborhood and month controls for more on this topic.

We next consider our month control estimates. All the months demonstrated statistically significant positive associations with the log odds ratio of home resale. Of note was the trend that September to December exhibited the highest association with resale. This makes sense, given the work of Schiller & Case (1987). They discussed how there is seasonal demand for different types of homes. Specifically, those homes demanded in the later months of the year are more likely to be smaller, lower-quality starter homes. Thus, they are outgrown more quickly and consequently have a higher chance of resale. However, home demand drops off in the early part of the year, and when it resumes, the trend is driven by families purchasing larger homes that are not resold as often (Shiller & Case, 1987). This fits with our observations that as a home gets more living area and lot size, its chance of resale decreases. Generally, it is not a novel observation that homes of lesser quality might resell more often. There can be many reasons for this. Those interested should refer to Clap & Giaccotto (1992) for additional information on this topic. Monthly controls have been used by Cheng, et al. (2018), Burkhardt & Flyr (2019), and Rasmussen (2021). However, those authors employed difference-in-difference and hedonic models, respectively. Further, the research our analytical logistic approach is based on did not include month controls (Pace & Zhu, 2019) (Marios, et al., 2019) (Ondrich, et al., 2003). Thus, we test the appropriateness of inclusion of month-fixed effects in appendix x: exclusion of neighborhood and month controls. We find that our model suffers absent month-fixed effects. Most likely, this is owing to the seasonality of home-type demand discussed by Schiller & Case (1987).

Year controls, like those for the month, display a highly significant positive relationship to the log odds ratio of home resales. However, 2015 was statistically insignificant. Year controls are an absolute necessity for our model. All the research on our topic has used such fixed effects. This is because controls for the effects of time-variant factors on your dependent variable are vital (Burkhardt & Flyr, 2019) (Cheng, et al., 2018) (Conklin, et al., 2020) (Marios, et al., 2019) (Ondrich, et al., 2003) (Pace & Zhu, 2019).

Finally, consider our primary independent variables of interest: the six-month lag of medicinal and recreational marijuana sales revenue. Our results for medicinal marijuana show that its association with the log odds ratio of home resale is statistically indistinguishable from zero. This conclusion matches the findings of Rasmussen (2021). This makes sense, as medicinal marijuana is at least partially bankable (Seefried, 2019b). However, there exists a highly statistically significant positive relationship between the amount of recreational marijuana sold and the probability of a home reselling six months later. That is, for an increase in the percentage of recreational marijuana revenue, there is an associated increase in the likelihood of homes reselling six months later. Rasmussen (2021) found a similar statistically significant association between recreational marijuana revenue and home prices.

Given the work of Waugh (1964), it makes sense that both Rasmussen (2021) and ourselves find the same six-month lag period best explaining the variation in home prices and resale probabilities, respectively. Consider that the value of a Denver County home today is positively associated with the amount of marijuana revenue generated six months ago. But by Waugh (1964), a market will not instantaneously reach its new equilibrium price. Instead, there will be a "causal chain" by which purchasing a home at time *t* impacts home values at time *t+1* (Waugh, 1964, p. 748). Thus, let *t* equal 1 month. In that case, it will take 1 month for home values to adjust to the purchasing of a new house. Hence, the positive association between the amount of recreational marijuana revenue generated six months ago and home values this month implies that the home was purchased five months after the associated recreational marijuana revenue was generated. Now suppose that dispensary owners are the buyers. But this means they would own the home one month before our observed positive association with home resale probabilities. This is logical, given the idea of homes being resold to launder money (Navarro, 2013). You see, you can resell a home in as little as a month (Zillow, 2021b). For these reasons, the lag structures of Rasmussen (2021) and our work here line up with the possibility of homes being bought up and quickly resold.

Now let us consider the marginal effects of our discovered relationship between the amount of recreational marijuana revenue generated and home resale probabilities. Holding all else constant at its mean value, we find a 1% increase above the mean of recreational marijuana revenue is associated with a roughly 0.33% increase over the mean probability that a home will resell. Put another way, for an approximate $78,919.20 increase above the mean amount of recreational marijuana generated, there is an associated 0.33% increase over the mean probability that a Denver County single-family home will resell in six months. Further, we calculate the overall change in home resale rates in appendix ix: percent change in probability of Denver home resale. There we find a roughly 68.12% increase in the likelihood of home resale associated with the marijuana revenue generated in Denver County. Let us also note that all our results presented in this section have proven robust to numerous alternative specifications.

Conclusion

There is robust evidence that dispensary presence and legalization of recreational marijuana are associated with increased Denver home values (Burkhardt & Flyr, 2019) (Cheng, et al., 2018) (Conklin, et al., 2020). Cheng, et al. (2018) posited that such increases could, at least in part, be related to "investors" buying up "more properties, for either [a] resale or rental purpose…" (Cheng, et al., 2018). Rasmussen (2021) picks up where Cheng, et al. (2018) left off and presents robust evidence that the investors might well be dispensary owners. Yet, the second part of Cheng, et al. (2018)'s comment is left unaddressed. That is, are the homes being purchased for resale or retention?

Thus, we set out to determine if there was a relationship between the amount of marijuana revenue generated in Denver County and the probability of home resale in that local. Seefried (2019a) indicated that dispensaries might well buy up Denver Homes. A likely purpose being to clean money and make it bankable (Seefried, 2019a). This fits with patterns of real estate money laundering practices detailed by Navarro (2013). If real estate is employed for money laundering purposes, Navarro (2013) indicates we should expect to see the resale probability of Denver homes increase along with recreational marijuana revenue. But this is what we observe. Specifically, we find that a 1% increase above the mean of recreational marijuana revenue generated is associated with a roughly 0.33% increase over the mean probability that a home will resell. That is, for a roughly $78,919.20 increase over the mean of recreational marijuana generated, there is an associated 0.33% increase over the mean probability that a Denver County single-family home will resell in six months.

Furthermore, in appendix ix: percent change in probability of Denver home resale, we find a roughly 68.12% increase in the likelihood of home resale associated with the amount of marijuana revenue generated in Denver County. That is, there was a 5.05 percentage point increase in the probability of a home reselling. Such a change is associated with the amount of marijuana revenue generated. This finding is in keeping with Cheng, et al. (2018). Recall they determined that the legalization of marijuana was associated with a 21-percentage point increase in the probability that a home would sell. The above also goes toward explaining why Cheng, et al. (2018) "Collectively, find evidence that recreational marijuana legalization leads to stronger housing demand and… no discernable effect on housing supply…" (Cheng, et al., 2018, p. 1598). Rasmussen (2021) hypothesized and found evidence favoring dispensaries investing in local real estate. We conclude that if dispensaries are Cheng, et al. (2018)'s investors, they appear to be reselling their purchases. Thus, it follows that the price of homes would increase for the reasons detailed in Rasmussen (2021), while the long-run supply of homes would remain relatively unaltered. That is, as the amount of marijuana revenue increases, there is an associated increase in home values and the likelihood of resale. Finally, our results have proven robust to alternative explanations such as increased migration, rising wages, and increased number of jobs.

It is possible that Snowden (2020) and the Rocky Mountain Drug task force are correct that illegal grow house activity is on the rise in Denver County. However, we do not find evidence in favor of that hypothesis here. In such an event, one would expect to see resale rates decrease as dispensary owners retain their illegal grow homes for marijuana production.

We hope our work in these pages sheds further light and motivates further investigation on this topic. For "there is not a single corner of the marijuana policy world that cannot be aided by additional analysis" (Hudak, 2020, p. 215). More than this, we believe our analysis contains information of benefit to city planners and policymakers alike. Together with the research of Rasmussen (2021), we observe that as the amount of marijuana revenue continues to rise in Colorado, the affordability of homes is likely to suffer. This stems from the fact that increased home values and resale rates are all associated with rising amounts of recreational marijuana revenue. Further, recall that Cheng, et al. (2018) found that low to middle-value homes were experiencing the most significant increases in value. Thus, the above findings could result in additional pricing out of disadvantaged segments of the Denver population. In fact, research indicates that such a thing is indeed happening in some regions of Denver (Voorde, et al., 2021). Thus, we join the plea of Rasmussen (2021) for policymakers to carefully consider the implications of the research on this topic and, by extension the benefits of granting legal banking access to dispensaries via the SAFE banking act (117th Congress, 2022). Such a policy has the potential to alleviate at least a modicum of the unusual and potentially detrimental market outcomes seeming to arise from the legal marijuana industry's lack of banking access.

CHAPTER 4-MALTHUS AND CONDORCET ON POPULATION: THE MISSING PIECE

Introduction

In 1798 Thomas Robert Malthus wrote: *An Essay on the Principle of Population, As It Affects the Future Improvements of Society; With Remarks on the Speculations of Mr. Godwin, M. Condorcet, and Other Writers.* (Malthus, 1798).

From such a title, at least two questions present themselves. One, what was Malthus's view on how population would affect "the Future Improvement of Society"? Second, how do Malthus's principles of population incorporate the "Speculations of" the listed writers, especially the Marque De Condorcet (Malthus, 1798, p. 1)? These two queries shall be the primary concern of this paper. Specifically, we will investigate the theoretical differences between Malthus and Condorcet's population growth models. Additionally, we examine how the Malthusian principles of population might be altered if the opinions of Condorcet were incorporated. In so doing, we shall see how Malthus and his population model avoid "misery" and "vice" (Malthus, 1798, p. 78). We then concern ourselves with possible reasons Malthus seems to have differed with Condorcet's views on population growth. Finally, we consider if the historical records have favored Malthus or Condorcet's beliefs on population. This is a paper of great interest, as to our knowledge, only one other has come close to investigating what we are about to. However, Winch (1996) does not look at the implications for the Malthusian population model of Malthus rebuke of Condorcetian population theory. Rather, it examines general theoretical differences between Malthus and Condorcet and presents reasons for their respective viewpoints (Winch, 1996). Thus, this paper treads on new and exciting ground in its examination of Malthus's famous population essay and Condorcet as a prognosticator of our modern world.

Condorcetian Model

We begin by looking at Condorcet's model for "the future improvement of society" (Malthus, 1798, p. 1). Such a model is presented in *Esquisse d'un Tableau Historique des Progress de L'esprit Humain* or *Sketch for a Historical Picture of the Progress of the Human Mind* (Winch, 1996) (Condorcet, 1955). To be fair, Condorcet did not create a model in the sense that Malthus did. That is, one employing elementary population statistics and food production rates in its creation (Condorcet, 1955) (Malthus, 1798). However, we can excuse this shortcoming as Condorcet's model was completed in a cellar before his capture and death in March 1794. For Condorcet, the *Sketch* was to serve as his final work, and he knew it (Avery, 1997). Hence, he poured forth all his life's knowledge to create a manuscript tracing human development from its beginnings up through the French Revolution (Condorcet, 1955). The text was published posthumously in 1795 (Avery, 1997). In his *Sketch,* Condorcet lays out his ten-stage progression of human development. The first involves the origins and creation of the "tribal society." Eight other stages follow, bringing the reader to Condorcet's own time (Condorcet, 1955, pp. 14-172) (Avery, 1997). However, the tenth and final stage is where Condorcet presents his model for "the Future Improvement of Society" (Condorcet, 1955) (Malthus, 1798, p. 1).

The tenth stage sets out to answer three questions regarding the future development of man. Firstly, shall there be an "abolition of inequality between nations"? That is, an end to causes of human suffering like wars, exploitation of weaker nations, etc.? Secondly, will there be a "progress of equality within each nation," such as decreasing wealth disparity, universal basic education, equality between the sexes, etc.? Lastly, shall the "true perfection of mankind" occur, and what will that mean? For such a task, Condorcet posits that "If Man Can, with almost complete assurance, predict phenomena when he knows their laws, and if, even when he does not, he can still, with great expectation of success, forecast the future on the basis of his experience of the past, why, then, should it be regarded as a fantastic undertaking to sketch…the future destiny of man on the basis of his history?" (Condorcet, 1955, p. 173). Thus, Condorcet bases his answers to the above three questions on his understanding of the past. It is the last of the above queries we will focus on as it pertains to humankind's ability to provide ample food for a growing population (Condorcet, 1955).

Condorcet begins answering the question of population and food production by stating 6 assumptions. The 1st assumption is that mental ability is partly hereditary. As Condorcet asserts, "May not our parents…hand on to us also that part of the physical organization which determines the intellect, the power of the brain…? Investigation of the human faculties…seem to give substance to such conjecture…" (Condorcet, 1955, p. 201). The 2nd assumption is that there is a continual growth of scientific knowledge from generation to generation. This happens despite the limits of the human mind and the population's level of education. Additionally, the knowledge gained will be employed more efficiently. The second assumption holds because yesterday's revolutions in understanding become today's common knowledge. This common knowledge is then built upon by the next generation, ad infinitum. As Condorcet says, “No-one has ever believed that the mind can gain knowledge of all the facts of nature…. But since, as the number of known facts increases, the human mind learns how to classify them and to subsume them under more general facts, and, at the same time, the instruments and methods employed in their observation and exact measurement acquire a new precision….so truths that were discovered only by great effort, that could at first only be understood by men capable of profound thought, are soon developed and proved by methods that are not beyond the reach of common intelligence” (Condorcet, 1955, pp. 184-85). Further, he states that “At the present time a young man on leaving school may know more of the principles of mathematics than Newton ever learnt in years of study or discovered by dint of genius, and he may use the calculus with a facility then unknown” (Condorcet, 1955, p. 196).

The 3rd of Condorcet’s assumptions is that “the progress of the sciences ensures the progress of the art of education which in turn advances that of the sciences” (Condorcet, 1955, p. 196). Simply put, as science advances so too will education, which will cause a further increase in science and so on. Thus, arises the 4th and fundamental assumption that “unlike mechanics where an increase of force means a decrease of speed, the methods that lead…to the discovery of truth [scientific knowledge] increases at once the force and the speed of its operations” (Condorcet, 1955, p. 185). What Condorcet seems to refer to is the equation in physics which shows that power (P) equals force (F) times speed (v). That is, $P=F*v$, and he is saying that P equals the growth rate of scientific innovation and is growing because both F and v are increasing. Now, let us put Condorcet’s description of the rate of scientific discovery in terms of mathematical growth rates. Consider that “geometric growth refers to the situation… where successive changes…differ by a constant ratio” and is defined as $a_{n+1} = a_n r$, where r is “the common ratio” (OECD, 2005) (Bittinger, et al., 2009, p. 636). Thus, $a_{n+1} = P$, while $a_n = F$ and $v = r$. Hence, Condorcet’s rate of scientific innovation is increasing at least geometrically. Thus, the 4th assumption is stating that scientific discovery improves at least geometrically (Condorcet, 1955, p. 185).

The 5th assumption says that “the mathematical and physical sciences tend to improve the arts that we use to satisfy our simplest needs….” (Condorcet, 1955, p. 192). That is, as mathematics and science improve, so does our ability to provide for everyday needs, like food. The 6th and final assumption holds that because the “theory” of the arts of production “depend on… sciences”, improvements in the means of production hold to the same assumptions as the sciences (Condorcet, 1955, p. 187). But because the rate of scientific “discovery” is minimally geometric, so is the rate of innovations in food production (Condorcet, 1955, p. 185). The way in which each of Condorcet's assumptions builds on one another prompted Joseph Spengler to state, "Condorcet's argument boils down to this: The forces making for progress will work…cumulatively" (Spengler, 1942, pp. 262-63).

Now, let us apply the Malthusian logic of population growth to the above 6 assumptions of Condorcet. Hence, suppose sufficient food to support the current population. Thus, there is a geometric increase in the population (Malthus, 1798, pp. 7-9). But by the 1st assumption, members of society with innate intelligence pass this trait to their children. Yet as these children grow, so does the number of the population able to add to the base of human knowledge. Next, the 1st and 2nd assumptions imply the birth and growth of a new generation. This generation brings with it a further increase in the amount and accessibility of knowledge to those of "common intelligence." Thus, new members of society with only "common intelligence" are added to the pool of individuals capable of augmenting the body of scientific understanding and innovation (Condorcet, 1955, p. 185). Now, by the 3rd assumption, all the previous increases in scientific knowledge and innovation will lead to growth in education. But increases in education result in yet more new members of society able to add to the bulk of scientific understanding and innovation. However, this implies even more education. So, we see why the 4th assumption holds. That is, increases in scientific knowledge and innovation increase at least geometrically. Finally, the 5th and 6th assumptions imply minimally geometric increases in scientific understanding and invention. However, such growth translates proportionally to increases in innovations to "satisfy our simplest needs…" (Condorcet, 1955, p. 192).

Basically, population growth precipitates an increasing amount and accessibility of scientific knowledge and innovation. In turn, such increases in scientific innovation lead to a proportional and minimally geometric rise in food production. Thus, to follow the Malthusian practice of assuming the worst-case scenario, we hold the increase in food production to be geometric. Consider a graphical representation of the above in figure 16. Figure 16's population growth numbers are based on the later presented Malthusian geometric population growth series (Malthus, 1798).

Due to the logic embodied in figure 16, Condorcet speculates that as the population grows, "A very small amount of ground will be able to produce a great quantity of supplies of greater utility or higher quality…Every type of soil will produce those things which satisfy the greatest number of needs…and which requires the least labour and least expenditure. So, without the need for sacrifice, methods of preservation and economy in expenditure will improve in the wake of progress in the arts of production…. So not only will the same amount of ground support more people, but everyone will have less work to do, will produce more, and satisfy his wants more fully" (Condorcet, 1955, p. 188).

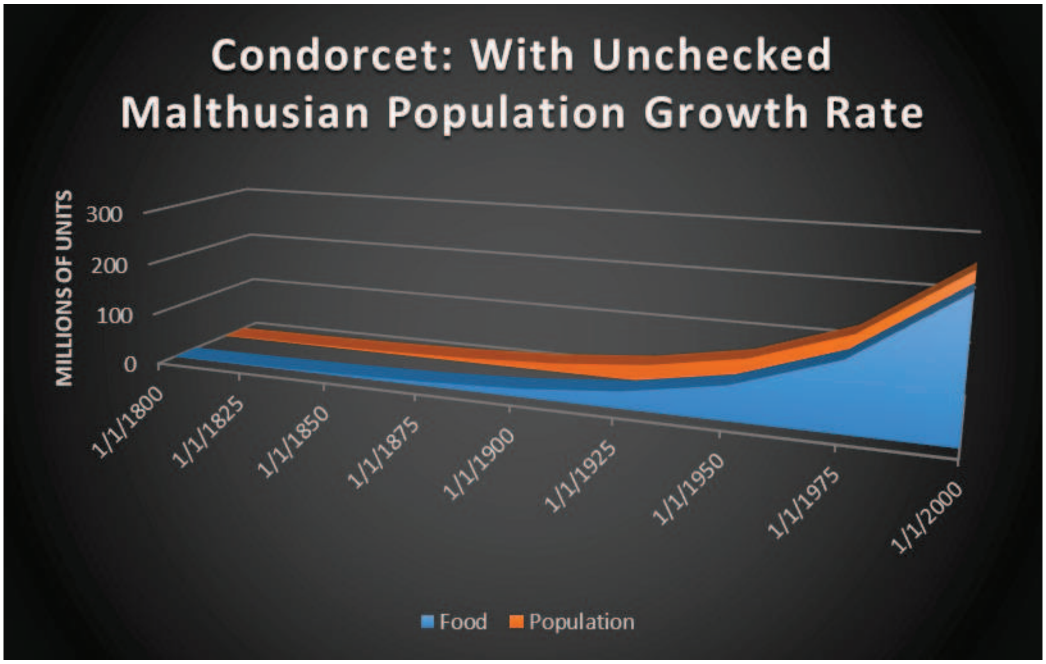

Figure 16. Condorcetian Food Production Growth, Given Malthusian Population Growth

However, what would be the results of an increase in the size of the population if the above assumptions failed to hold and we reached "a point… beyond which all further improvement is impossible?" As Condorcet asks, "might there…come a moment…when, the number of people in the world finally exceeding the means of subsistence, there will in consequence ensue a continual diminution of happiness and population, a true retrogression, or at best an oscillation between good and bad?" (Condorcet, 1955, p. 188) . Condorcet answers, "But even if we agree that the limit will one day arrive, nothing follows from it that is in the least alarming as far as either happiness of the human race or its indefinite perfectibility is concerned; if we consider that, before all this comes to pass, the progress of reason will have kept pace with that of the sciences, and that the absurd prejudices of superstition (religion) will have ceased to corrupt and degrade the moral code by its harsh doctrines instead of purifying and elevating, we can assume that by then men will know that…they have a duty towards those who are not yet born…not to give them existence but to give them happiness." Thus, "Their (future generations) aim should be to promote the general welfare of the human race or the society in which they live or the family to which they belong, rather than foolishly to encumber the world with useless and wretched beings. It is, then, possible that there should (could) be a limit to the amount of food that can be produced, and consequently…the size of the population of the world, without this involving that untimely destruction of some of those creatures who have been given life….” (Condorcet, 1955, p. 189).

Essentially, Condorcet is saying that if the ability to innovate new means of food production is ever thoroughly exhausted, society will have advanced to the point where they engage in either abstinence or outright birth control. Thus, the number of people worldwide will match its ability to feed them. Further, this will happen without a mass die-off of individuals because future generations can predict the sustainable number of children to have (Condorcet, 1955).

Malthusian Model

We shall continue by examining Malthus’s population model. We consider the model laid out in the first edition of his essay. However, we note an amendment first appearing in the second edition (Malthus, 1798) (Malthus, 1803).

Chapter one, book one, starts with a masterful bit of rhetoric whereby Malthus seeks to answer the question of “whether man shall henceforth start forwards with accelerated velocity towards illimitable…improvement, or be condemned to a perpetual oscillation between happiness and misery?” Malthus is asking whether Utopians, like William Godwin and Condorcet, are correct in their views on population? Or perhaps, it is those individuals Malthus refers to as “the advocates of the present order of things” that espouse the truth (Malthus, 1798, p. 28)? Malthus seems to prefer the former group’s views. Yet, he doubts the practicality of such utopian visions. This is because of two postulations/laws; “First, that food is necessary to the existence of man. Secondly, that the passion between the sexes is necessary and will remain nearly in its present state.” Malthus’s reasoning for why the above will always be true is that it has always been true, and therefore “we have no right to conclude that they (the postulations) will ever cease to be what they now are….” Additionally, “Assuming my postulata…. the power of population is indefinitely greater than the power of the earth to produce subsistence for men.” Specifically, “Population, when unchecked, increases in a geometrical ratio. Subsistence increases only in an arithmetic ratio.” Malthus saw the above as a check on population and an insurmountable obstacle to a utopian world free of an individual’s “anxiety about providing the means of subsistence for themselves and their families." Thus, the "perfectibility of the mass of mankind" will remain an elusive dream (Malthus, 1798, pp. 4-5).

In chapter two of book one, we are introduced to why Malthus believes in different growth rates for population and food production. He holds that an unchecked population will grow at least geometrically. Yet the earth's ability to provide only increases at most arithmetically. America is an example of nearly unchecked population growth owing to its "ample" means of subsistence. We are told that every twenty-five years, the population doubles. However, even America had some checks on population growth at the time. Thus, Malthus sees the above rate as an underestimation of the speed at which a genuinely unchecked population will grow (Malthus, 1798, p. 7) (Hollander, 1997). Yet, to err on the side of caution, he assumes a geometric unchecked population growth rate. Regarding the growth rate of subsistence, Britain is used as an illustration. Here Malthus says that "the whole produce" of the island will increase by an amount equal to what it currently produces every twenty-five years. He goes on to say that even "the most enthusiastic speculator cannot suppose a greater increase than this" (Malthus, 1798, p. 7). Thus, Malthus again gives the benefit of the doubt to his skeptics and assumes the upper bound of arithmetic food production growth.

Now let us understand what the above means for population growth. Consider starting with a population of 1 million souls and 1 million bushels of corn. Then we might have the sequence $1,2,4,8, \ldots = \sum 2n$ etc. for population growth and $1,2,3,4, \ldots . = \sum 1 + n$ etc, for the increase in corn production (Malthus, 1798, p. 8). Consider a graphic representation of the above population and food production growth rates in figure 17.

We can see in figure 17 that an unchecked population would quickly outgrow its means of subsistence. Further, Malthus says that population is always increased before subsistence. The result is that the population increases and then suffers die-offs until the population is equal to the food produced. Further, notice that this takes about five years. This is because it was infant and child mortality that represented the lion's share of those lost to "misery" (Malthus, 1798) (Blaug, 1958). This brings us to the heart of the prediction of Malthus's essay and his model.

Yet, before considering his model, we must understand the following Malthusian definitions. First, "misery" represents population decreasing effects visited upon society. That is, starvation, disease, war, etc. (Malthus, 1798, p. 54). Meanwhile, "vice" was "the sort of intercourse which renders some of the women of large towns unprolific; a general corruption of morals with regard to the sex, which has a similar effect; unnatural passions and improper arts to prevent the consequences of irregular connections." Simply put, "vice" referred to what Malthus saw as immoral sexual activities like abortion, contraception, prostitution, homosexuality, etc. (Malthus, 1798, p. 152) (Malthus, 1983, p. 250).

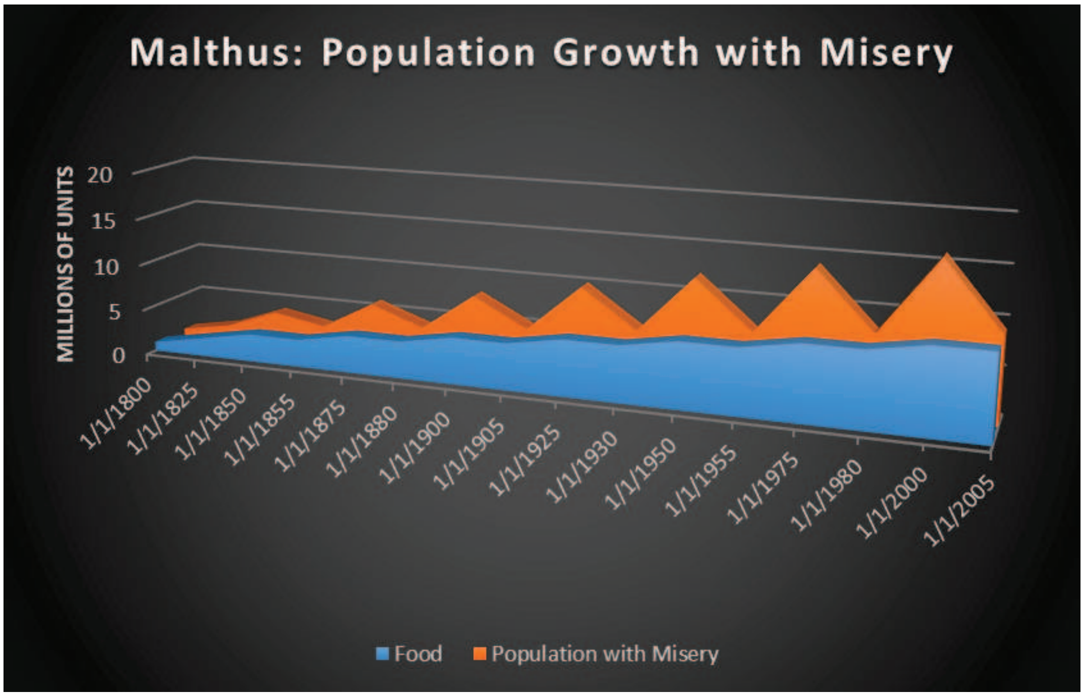

Figure 17. Unchecked Malthusian Population Growth vs. Food Production Growth

Now let us consider the model itself. First, suppose the people of a hypothetical society have enough food to live decently. Thus, they conceive children because "the tendency to a virtuous attachment is so strong that there is a constant effort towards an increase of population" (Malthus, 1798, p. 9). Additionally, parents believe they can support children since sufficient victuals exist. However, as babies are born and weaned, the per capita food available decreases. This leads to misery of the people. Further, as children mature, there is an overabundance of labor and a scarcity of provisions. This situation drives down wages and increases prices. Hence, workers must toil longer hours to survive, and yet more misery results. But now people engage in vice to avoid having children, for which food is insufficient to support. Further, society desires more production and has a surplus of cheap labor. This leads to the cultivation of new land. Hence, food and provisions increase until the surviving population is comfortable again. Now the stage is set for the cycle to repeat itself ad infinitum. Thus, Malthus concludes that "the superior power of population cannot be checked without producing misery or vice…." (Malthus, 1798, p. 11). For all the above reasons, Malthus believed humanity was destined to endure a "perpetual oscillation between happiness and misery" (Malthus, 1798, p. 1). However, starting in the second edition of his essay, Malthus allows for a third check on population, "the prudential check," which is the voluntary postponement of marriage. Further, during marital postponement, celibacy is practiced (Malthus, 1803, p. 599).

Hybrid Model

What might it mean if Malthus had agreed with and included the assumptions of Condorcet in his model? To begin, reconsider the postulations of Malthus and the assumptions of Condorcet. That is, "First, that food is necessary to the existence of man. Secondly, that the passion between the sexes is necessary and will remain nearly in its present state" (Malthus, 1798, p. 4). Now add the assumptions of Condorcet, that; 1st mental ability is partly a hereditary trait, 2nd there is a continual growth of human scientific knowledge and the effectiveness of its use from generation to generation, 3rd, as science advances so too will education, which will cause a further increase in science, 4th that the growth of scientific knowledge is at least geometric, 5th that as science improves it increases our ability to provide for our everyday needs, and thus 6th that the rate of increases in food production is at least geometric (Condorcet, 1955).

From the above, we draw slightly different conclusions than either Condorcet or Malthus alone. Like Malthus, we assume a geometric population growth rate (Malthus, 1798). However, while Malthus supposes that subsistence increases arithmetically, we will assume that it can grow geometrically (Malthus, 1798). We do this because of Condorcet's previous chain of logic.

Now, suppose the people of a hypothetical society have enough food to live decently. Hence, they conceive children because "the tendency to a virtuous attachment is so strong that there is a constant effort towards an increase of population" (Malthus, 1798, p. 9). Additionally, sufficient provisions exist so parents believe they can support their children. However, once the infants are born and weaned, less food is available per person. This means that "the poor…must live much worse" (Malthus, 1798, p. 9). But, while the number of people has increased, so has the quantity of mentally talented individuals available to innovate new and more productive food production methods. Yet, when the children mature, there is an overabundance of labor and a scarcity of provisions. This drives down wages and increases prices. However, with a new generation's maturation comes an increased knowledge base that can devise new innovations. Additionally, the food shortage will provide a Malthusian "goad of necessity," further boosting the rate of innovation (Winch, 1996, p. 54). Because as Condorcet said, “the need for new methods in fact only arises in circumstances that give rise to new methods…” (Condorcet, 1955, p. 186). Thus, while an increase in the population means more mouths to feed, a likely decrease in wages, and an increase in prices, it also means a geometric increase in the rate of food production.

That is, we have cheap labor, more efficient means of food production, and increased demand for provisions. Hence, food production will rise geometrically to meet the needs of the increased population. All this will happen without humanity enduring the Malthusian mass die-offs and periods of “vice” (Malthus, 1798, p. 19). Thus, the simple hybrid model shows how a geometric increase in population can lead to at least a geometric rise in food production. This, in turn, sets the stage for another round of predominately misery and vice free population growth. We say “predominately” because there will likely be some degree of societal hardship as children grow and learn before adding to the pool of innovation. However, writers such as Adam Smith told of children innovating productivity-increasing devices at young ages (Smith, 1937). Additionally, the mere presence of children provides its own motivation regarding food production by the existing adult population. Thus, we assume that any lag between population growth and increased food production would be minimal. Consider figure 18, which is a graphical representation of the above trends of the hybrid model’s population and food production growth.

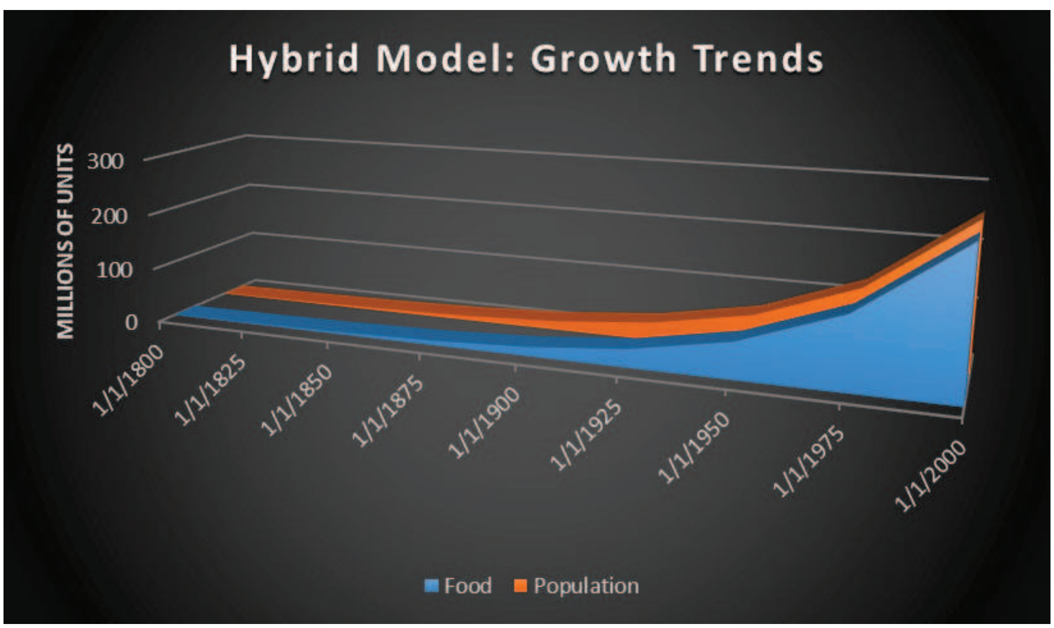

Figure 18. Hybrid Population Growth vs. Food Production Growth

Basically, the hybrid model matches Condorcet's and shows that society can escape Malthus's dire conclusion that "the superior power of population cannot be checked without producing misery or vice…." (Malthus, 1798, p. 11). This can be achieved via the inclusion of the assumptions of Condorcet regarding population growth. Further, the hybrid model and its conclusions make sense, given that the crucial flaw in Malthus's argument which was "that population increase was only a problem relative to the means of production…" (Ross, 1998, p. 30). Is it any wonder then that Donald Winch says of Condorcet that "he predicted exactly those methods by which mankind had escaped the Malthusian trap…." (Winch, 1996, p. 49).

Why Malthus Disagreed with Condorcet

Malthus's essay was clearly a rebuttal to existing views regarding population. Specifically those of Condorcet. As E.A. Wrigley notes, "When Malthus wrote his first *Essay on the Principle of Population* one of his chief aims was to refute the views expressed by Condorcet…." (Turner, 1986, p. 3). Thus, why did Malthus disagree so strongly with Condorcet's observations that he wrote an entire essay on the matter? Mainly, why did Malthus seem to object to a world where a geometrically increasing population leads to at least a geometrical increase in food production?

We will present six reasons that such disagreement seems to have existed. To begin with, "Practical men who believe themselves to be quite exempt from any intellectual influence, are usually the slaves of some defunct economist" (Keynes, 1935, p. 383). These words by John Maynard Keynes provide a succinct presentation of perhaps one of the most potent reasons for Malthus's objection to Condorcet's model of population growth. Specifically, we propose that the differing degrees to which Malthus and Condorcet put stock in the views of Francois Quesnay, Anne Robert Jacques Turgot, and Adam Smith, played a central role in their divergent opinions on the potential for food production.

To understand such an argument, we must begin by examining the Physiocrats. Particularly the views of Quesnay and Turgot. The initial aim of Physiocratic inquiry was to determine the source of economic growth. The discipline seems to have stemmed from a French interest in winning the Seven Years' War (Vardi, 2012). Physiocracy means "reign of nature," for nature sits at the heart of such an economic doctrine (Vardi, 2012, p. 6). It is she who bestows her "gift" to the agricultural workers and thus allows for economic growth to take place (Meek, 1962, p. 388). The logic for such a Physiocratic belief is summed up by the question, "Did not 100 bushels of wheat yield a crop of 300 or 400 bushels. Whence came these additional bushels if not from nature's generosity" (Heilbroner, 1997, p. 35)? Specifically, the Physiocrats held that the only source of surplus, or "net product," came from the agricultural sector because "in agriculture 'nature labours along with man'…" (Meek, 1962, p. 388). Thus, agricultural workers were the only class capable of generating a surplus (Vardi, 2012). As the renowned Physiocrat Quesnay stated, "it is only those who cause to be generated from landed property products whose value exceeds their costs who produce wealth or annual revenue" (Meek, 1962, p. 96). Quesnay was not alone in such a belief. The "most eminent physiocrat," Turgot said, "The husband [agricultural worker] is the only one whose industry produces anything over and above the wages of labour. He is therefore the unique source of all wealth" (Turgot, 1795, p. 9). But by such reasoning, Quesnay and Turgot determined that manufacturing industries and their workers were a "sterile" or "disposable" class because "they consume as much as they produce…and no surplus wealth results from it [manufacturing sector] " (Meek, 1962, pp. 20,96) (Turgot, 1795, p. 17).

One of the most historic contributions of the Physiocrats was the introduction of the first graphic illustration of an economy. It was Quesnay's now famous *Tableau Economique*. It depicted the "productive class," laboring with the land to produce national growth (Meek, 1962, pp. 21,108-114,319). This prediction is predicated on the size of the "gift of nature" to the "productive class" (Meek, 1962, pp. 21,388). Specifically, the Physiocrats held that under certain circumstances, what was given to nature would be doubled (Meek, 1962). That is, Physiocratic agricultural workers were the only economic class of workers to enjoy increasing returns to scale (Spengler, 1942). Such a belief in increasing returns to agricultural work seems to have been shared by Turgot. This is evidenced by his previous statement that only the agrarian worker can generate a surplus (Turgot, 1795). In fact, Turgot states that "the work of the cultivator produces not only his own wages, but also that revenue which serves to pay all the different classes…their salaries" (Turgot, 1795, pp. 17-18). Hence, the inputs used by the agricultural worker must have increasing returns (Turgot, 1795).

Consider an example of agricultural input doubling. Given 300 Livres worth of cereal grains to plant, farmers would harvest a crop worth 600 Livres. But a necessary condition for the agricultural doubling of inputs was that agrarian workers had the proper tools to carry out their tasks. Yet such instruments were created by the "sterile" sector (Meek, 1962, pp. 128-138). Hence, while the manufacturing sector might not generate a surplus, some goods they produced were vital for agricultural growth. Further, we can see that the innovation of agricultural implements was important to Physiocratic growth. Note that the Physiocratic *Tableau* had a third class of "proprietors. This class consisted of the landowners…" (Meek, 1962, pp. 20,128-138).

Now, what might an increase in population mean for the Physiocratic model? Assume the population increase occurred in proportion to the existing size of the three sectors of the economy. Thus, the most significant increases would be seen in the agricultural and manufacturing sectors. With more manufacturing workers, you would likely have increased production of machinery and agricultural implements. These are necessary for nature to double her inputs. Further, we have more agrarian workers using the increased number of tools. Thus, as the population increases, it seems food output also does. That is, the Physiocratic model results in sufficient food production. This is likely a result of increasing returns to agricultural inputs and, thus a doubling of the value of inputs to food production.

The above is an economic world unblighted by the specter of Malthusian doom. No, this view of population growth is much more like Condorcet's utopian model. Consider Condorcet's belief that a population increase leads to advances in knowledge, education, and thus food production. Such logic appears grounded in Physiocratic thought. According to Vardi (2012), Physiocrats, especially Quesnay and Turgot, were concerned with the role of education in a population's ability to understand and efficiently harness the doubling effects of nature. In fact, Quesnay was so convinced of the role of education in national growth that he advised king Louis XV to "establish public schools" (Rothschild, 2001, p. 226). Such a belief was shared by Condorcet, who remarked that if a "universal system of education" were adopted, "there would be a proportionate increase in the number of men destined by their discoveries to extend the boundaries of science" (Condorcet, 1955, p. 186). Another similarity between Physiocratic thought and Condorcet is that both recognize the role of mechanical assistance in sufficient food production. Recall the Physiocratic understanding that to double inputs, agricultural workers require the proper mechanical assistance from the "sterile" sector. Compare this belief with Condorcet's 5th assumption that "the mathematical and physical sciences tend to improve the arts that we use to satisfy our simplest needs….". Here the "mathematical and physical sciences" would most closely align with the Physiocratic "sterile" sector of the economy (Meek, 1962, pp. 128-138) (Condorcet, 1955, p. 192).

Thus, Condorcet's *Sketch* and the writings of Quesnay and Turgot appear to have shared the recognition that the innovative manufacturing sector was the one supplying agrarian workers with the means of efficient food production (Meek, 1962) (Condorcet, 1955). So, all three men's ideas seem to arrive at a utopian world. That is, one where an increasing population brings with it sufficient increases in food production to feed its new citizens. However, Quesnay, Turgot, and Condorcet all seem to have realized that an overabundant population was a potential problem. Yet, it could be overcome by proper education, innovation, and maximization of nature's fertility (Condorcet, 1955) (Turgot, 1795) (Spengler, 1942). Thus, the most striking similarity between Condorcet's model and Physiocratic ideology is the former's conclusion that the soil can be made productive enough to support an increasing population. This is nothing if not the Physiocratic idea of "nature's gift" in action (Condorcet, 1955) (Meek, 1962, p. 388).

But is it a mere coincidence that we see Physiocratic influences in Condorcet's model? It hardly seems so. Consider the close ties existing between Condorcet and two of the greatest Physiocrats, Quesnay and Turgot (Vardi, 2012) (Rothschild, 2001).

First, Quesnay and Turgot were both members of a small Physiocratic social circle (Williams, 2004). Not only this, but they often dined together. Further, such dinners usually focused on the discussion of agricultural matters. In fact, Turgot saw Quesnay so frequently that he started calling Quesnay the "good doctor" (Vardi, 2012, p. 48). Further, in 1766 Turgot "aligned himself with the…principles of political economy associated with Quesnay" in his *Reflexions sur la formation et la distribution de richesse* (Williams, 2004, p. 230). For all the above reasons, Spengler calls Turgot a "disciple" of Quesnay (Spengler, 1942, p. 263).

Secondly, Condorcet was also acquainted with Quesnay and his teachings. The 18th-century historian William Playfair describes "meetings of Quesnay, Turgot, Condorcet and Diderot…" taking place and having a significant influence on the progression of Physiocratic events in France (Rothschild, 2001, p. 18). Third, starting in 1770, Condorcet and Turgot became "close friends" and allies (Rothschild, 1992, p. 1199) (Williams, 2004, pp. 12-13) (Avery, 1997, p. 2) (Rothschild, 2001, p. 19). In fact, Turgot is credited with having "ignited" Condorcet's interest in economics (Williams, 2004, p. 18). Further, "Turgot was a proponent of physiocratic views" who "had Condorcet's enthusiastic support…." (Williams, 2004, p. 18). Little wonder then that Turgot and Condorcet agreed on many economic matters and shared the same economic "notion of material improvements…." (Vardi, 2012, p. 266) (Rothschild, 2001, p. 161). Additionally, Turgot and Condorcet actively collaborated on many engineering and economic projects. Such collaborations included defending the free trade of grain and notions of equilibrium

(Williams, 2004). Further, both men were philosophes, a small group of writers giving "expression to the aspirations of the emerging bourgeois class." For all the above reasons, Spengler repeatedly refers to Condorcet as a "disciple" of Turgot (Spengler, 1942, pp. 258,285). After Turgot's death in 1781, Condorcet acknowledged the influence Turgot had upon him by writing a biography of the man he had come to consider his "spiritual father" (Vardi, 2012, p. 253) (Rothschild, 1992, p. 1205). Basically, Quesnay and Turgot were close confidants of Physiocracy, while Quesnay and especially Turgot influenced Condorcet. As Joseph Spengler says of Condorcet, he not only "accepted the views of Turgot and the physiocrats…." but was "Essentially a popularizer of economic doctrines…of Turgot…" (Spengler, 1942, p. 259).

Thirdly, Condorcet was initially an avid supporter of the ideals of the French Revolution (Avery, 1997). But his backing of such values is hardly unexpected. Consider that the principles of the French Revolution were thought by many (Eugene Daire, Edmund Burke, Alex De Tocqueville, and François Furet) to be a direct realization of Physiocratic philosophy (Vardi, 2012) (Rothschild, 2001). From all the above, we see that the similarities between the Physiocratic ideology and Condorcet's model are anything but mere coincidence. No, a clear progression of ideology from Quesnay and Turgot to Condorcet seems to exist (Avery, 1997) (Vardi, 2012) (Spengler, 1942) (Rothschild, 2001).

But while Condorcet was a follower of many Physiocratic notions and "venerated" Turgot, he was not a Physiocrat (Williams, 2004, pp. 228-229). Instead, he used Physiocratic ideology as grist for his own economic mill. Yet Physiocratic thinkers were not the only economists influencing Condorcet. No, there was another man greatly responsible for Condorcet and his model of population growth: Adam Smith (Rothschild, 2001) (Rothschild, 1992) (Williams, 2004). This is not shocking, given the degree of Physiocratic influence and association with Smith.

Smith's relationship with Physiocracy apparently began around 1763-1766. That was the time Smith visited Europe, particularly Paris. There, Smith repeatedly met with Quesnay to discuss the latter's Physiocratic views (Medema & Samuels, 2013). The leading Physiocrat Dupont de Nemours fondly recalled a time when he and Smith "were disciples together in the home of Mr. Quesnay" (Rothschild, 2001, p. 66). During this time, Smith "began serious work on…, *The Wealth of Nations*" (Heilbroner, 1997, p. 55). That Smith's newfound dedication to writing the *Wealth of Nations* coincided with his association with Quesnay and the Physiocrats is anything but a coincidence (Rothschild, 2001). In fact, "Smith would have dedicated *The Wealth of Nations* to Quesnay had not the doctor died before its publication" (Heilbroner, 1997, p. 35). It is not surprising then that Smith summarizes Physiocratic thinking by saying, "This system,…with all of its imperfections is…the nearest approximation to the truth that has yet been published upon the subject of political economy…." (Smith, 1937, p. 642). However, Smith's exposure to Physiocratic ideas was not solely at the hands of Quesnay. Smith also met Turgot "on several occasions in Paris in 1776." Further, Smith maintained "close intellectual connections" with Turgot until the latter's death in 1781 (Rothschild, 1992, p. 1197). Thus, there exists "extensive literature about Turgot's influence on Smith." More than this, Smith said of Turgot that he was "a person whom I remember with so much veneration…" (Rothschild, 1992, p. 1205). Hence, Physiocracy's influence on Smith is very evident. In fact, in 1805, William Playfair noted a striking "coincidence of reasoning with the French Oeconomists" on Smith's behalf. Playfair believed this resulted from Smith's interactions with Physiocratic thinkers (Rothschild, 2001).

But of course, Smith was more than just a "disciple" of Quesnay and Physiocracy (Rothschild, 2001, p. 66). While he recognized Physiocracy as "the nearest approximation to the truth that has yet been published upon the subject of political economy…," he also realized a fallacy lay at its heart (Smith, 1937, pp. 639-642). As he put it, "the capital error of this system [Physiocracy]…seems to lie in its representing the class of artificers, manufacturers and merchants, as altogether barren and unproductive" (Smith, 1937, p. 639). Specifically, Smith understood that it was not the class of a worker which determined their productive abilities. In Smith's words, "farmers and country labourers can no more augment… the annual produce of the land and labour of their society, than artificers, manufacturers, and merchants. The annual produce of the land and labour of any society can be augmented only in two ways; either first, by some improvement in productive powers of the useful labour actually maintained within it; or, secondly, by some increase in the quantity of that labour." (Smith, 1937, pp. 640-641). Basically, a worker's ability to create a surplus stemmed not from toiling alongside nature to receive her "gift" but instead from that worker's productivity, or hours worked (Meek, 1962, p. 388) (Smith, 1937).

Regarding the first method of surplus creation, Smith says, "the productive powers of…labour depends, first, upon the improvement in the ability of the workman: and secondly, upon that of the machinery with which he works. But the labour of artificers and manufacturers, as it is capable of being more subdivided, and labour of each workman reduced to a greater simplicity of operation, than that of farmers and country labourers, so it is likewise capable of both these sorts of improvement in much higher degree" (Smith, 1937, p. 641). Hence, agricultural workers had no monopoly on the production of national surpluses. In fact, agrarian workers might be less productive than manufacturing workers. Like the Physiocrats, Smith understood machinery's vital role in surplus creation. Smith merely took the idea one step further by realizing that this was not only true in agriculture (Smith, 1937). This is a perfect example of how Smith took Physiocratic ideas and grasped their more general applications.

Secondly, Smith believed increased productivity was more than just a matter of efficient machinery. He understood that the division of labor was the most crucial factor allowing increased worker productivity and surplus creation. He saw the division of labor as a process by which a task was subdivided into many parts. Further, each subtask would often become the sole occupation of individuals. But as people specialized in subtasks, the overall productivity of the entire enterprise was increased beyond the sum of each worker's contribution to output. Smith's pin factory is a classic example of the benefits of the division of labor. There Smith relates how the entire process of making a pin has been subdivided into "about eighteen distinct operations." But it was often the case that one person would perform several tasks. Thus, pin-making was typically divided among ten individuals. Smith continues by describing how "Those ten persons…could make among them upwards of forty-eight thousand pins in a day. Each person, therefore, making a tenth part of forty-eight thousand pins, might be considered as making four thousand eight hundred pins in a day. But if they had all wrought separately and independently…they could not each of them have made twenty, perhaps not one pin in a day" (Smith, 1937, pp. 4-5). Smith provides three reasons why the division of labor led to increased productivity; "increase in dexterity in every particular workman…", "the saving of the time…commonly lost in passing from one species of work to another…", "and lastly, to the invention of a great number of machines which facilitate and abridge labour, and enable one man to do the work of many" (Smith, 1937, pp. 7-10). However, there was one necessary component for any increase in the division of labor to occur: there had to be a large enough market. That is, a sufficient population for the division of labor to be practical. For "when the market is very small, no person can have an encouragement to dedicate himself entirely to one employment, for want of the power to exchange all that surplus part of the produce of his own labour…." (Smith, 1937, p. 17). Basically, if there were not enough individuals to trade with, then any division of labor would not allow personal survival. Instead, in small markets like "The Highlands of Scotland, every farmer must be butcher, baker and brewer for his own family" (Smith, 1937, p. 17). But as the population grew, so did the division of labor, leading to increased overall productivity. Further, as market size (population) increased, new trades offered the possibility of providing a living. Smith's example of this phenomenon is the porter (Smith, 1937).

Now recalling the above, consider a population increase in the Smithian world. As the population grows, it leads to a larger market size. Thus, greater industrial division of labor and increased production of agricultural implements. But remember, Smith recognized that agrarian workers would also benefit from larger markets and the resulting division of agricultural labor. That is, agrarian workers also enjoy an increased division of labor, albeit to a lesser degree than manufacturing (Smith, 1937, p. 641). Finally, increased division of labor leads to more innovation of "machines which facilitate and abridge labour…." But all the above means that our post-population boom agricultural workers can "do the work of many" pre-population boom farmers (Smith, 1937, p. 7). Thus, population growth likely results in an increased rate of food production surpassing the Malthusian arithmetic rate and could even result in "universal opulence" (Malthus, 1798) (Smith, 1937, p. 11).

All the above serves to illustrate one thing: aspects of Condorcet's model seem adherent to Smithian views on the division of labor and surplus creation. To see this, recall Condorcet's assumptions. First, remember Condorcet's 2nd assumption of a continual growth of scientific knowledge and effective implementation from generation to generation. This is because the revolutions in understanding yesterday have become the common knowledge of today. This common knowledge is then built upon by the next generation, and so on. As Condorcet says, "as the number of known facts increases, the human mind learns how to classify them and to subsume them under more general facts, and, at the same time, the instruments and methods employed in their observation and exact measurement acquire a new precision….so truths that were discovered only by great effort, that could at first only be understood by men capable of profound thought, are soon developed and proved by methods that are not beyond the reach of common intelligence" (Condorcet, 1955, pp. 184-85). Further, he states that "At the present time a young man on leaving school may know more of the principles of mathematics than Newton ever learnt in years of study or discovered by dint of genius, and he may use the calculus with a facility then unknown" (Condorcet, 1955, p. 196). But the above mirrors Smith's division of labor. What Condorcet is saying is that as the population increases, the artificers and scientists become more specialized and thus can refine their field of knowledge. This occurs in much the same way that Newton refined Calculus to become a more efficient scientific tool. This tool also acquired greater accessibility to more individuals. Thus, like Smith, Condorcet's 2nd assumption recognizes that agricultural workers have no monopoly on producing surpluses. Also, when Condorcet says that "the instruments and methods employed in…observation and exact measurement acquire a new precision," he demonstrates a Smithian understanding of innovation springing from the division of labor (Condorcet, 1955, pp.

184-185). But to fully realize the role division of labor plays in Condorcet's model, we continue his remaining assumptions. The 3rd assumption is that as science advances, so too will education. But as education increases, it will cause a further growth of scientific knowledge, ad infinitum. 4th, we have increases in scientific knowledge growing at least geometrically. 5th, as science improves, it allows us to apply those scientific innovations to food production. Thus, by the 6th assumption, the rate of food production increases at least geometrically (Condorcet, 1955). But the above chain of logic is nothing if not an illustration of how scientific workers can create a surplus via minimally geometric rates of scientific discovery. Such innovation is then used to increase food production, at least geometrically. Thus, Condorcet and Smith both recognize the vital role of innovation in the surplus creation of non-agricultural sectors. Yet, Condorcet's model is also Physiocratic in that it identifies the central role of education, machinery, and innovation in nature's ability to double the inputs given to her (Meek, 1962).

In truth, Condorcet's model seems to have the fingerprints of both Physiocracy and Smith in its DNA. However, it is not surprising that Condorcet's model shows influences of both Physiocratic and Smithian thought, given the previously discussed close connections between Condorcet, Quesnay, Turgot, and Smith. Such links prompted Spengler to say of Condorcet that he was a "disciple of Turgot, and A. Smith," while both Smith and Turgot have been shown to be disciples of Quesnay (Spengler, 1942, pp. 258,263) (Rothschild, 2001, p. 66). In fact, we have already seen the influence Quesnay and Turgot had on Condorcet and Smith (Avery, 1997) (Rothschild, 2001) (Williams, 2004) (Spengler, 1942). However, what of the direct connections between Condorcet and Smith? There are so many linkages between these men that Emma Rothschild wrote an entire book "principally concerned" with discussing the various and sundry ways that Smith and Condorcet are ideologically related (Rothschild, 2001, pp. 8,32-33). For instance, Condorcet, Smith, and Turgot all agreed bartering was a definingly human characteristic, wrote about the benefits of free trade, supported a laissez-faire approach to economics, and favored various aid programs for the poor (Rothschild, 1992) (Williams, 2004) (Rothschild, 2001) (Spengler, 1942). These are a few examples of the various subjects Smith, Condorcet, and Turgot (to a lesser degree) agreed on (Rothschild, 2001).

However, more relevant than the above is that Condorcet, Smith, and Turgot all recognized the importance of the division of labor. Turgot's *Reflections* were published ten years before *Wealth of Nations*. Yet it discusses the near impossibility of a man making his shoes from scratch (Turgot, 1795). Such a task requires specialized equipment and separate operations that prevent one man from accomplishing the work alone. Thus, Turgot concludes that “If the same man who cultivates on his own land these different articles…to supply his own wants, was obliged to perform all the intermediate operations himself, it is certain he would succeed very badly” (Turgot, 1795, p. 4). Turgot’s example is nothing if not an agricultural forerunner of Smith’s pin factory (Smith, 1937). But recall Spengler repeatedly refers to Condorcet as a “disciple” of Turgot. So it is easy to understand how Condorcet also came to understand the merits of Smith’s division of labor argument. This is evidenced by Condorcet’s repeatedly considered assumptions (Spengler, 1942, pp. 258,285) (Rothschild, 2001) (Condorcet, 1955). Additionally, Quesnay, Turgot, Smith, and Condorcet all believed man a generally rational creature (Vardi, 2012) (Spengler, 1942) (Rothschild, 2001) (Williams, 2004). That Smith, Turgot, and Condorcet, should have so many personal and ideological similarities hints at the fact that all three engaged each other in “correspondence, or reciprocal study…” (Rothschild, 2001, p. 19). Turgot owned and studied *The Wealth of Nations*. As for Condorcet, he and his wife “edited,” translated, and provided feedback for several of Smith’s works. This material included *The Wealth of Nations* and *The Theory of Moral Sentiments* (Rothschild, 2001, p. 87) (Rothschild, 1992, p. 1197) (Williams, 2004, p. 13).

Thus, the entirety of our above discussion reveals a logical progression of economic ideology. It starts from the Physiocrats, runs to Smith, and culminates in a synthesis of Physiocratic and Smithian concepts present in Condorcet’s Utopian Model. Thus, it has been said that together “the Turgot’s, the Condorcet’s, the Smith’s” are the “fathers of the science” of political economy (Rothschild, 2001, p. 4).

Hence, Malthus's essay on population was more than a refutation of Condorcetian Utopianism. It represented a departure from the culmination of Physiocratic and Smithian ideologies on population. The fact that Malthus was refuting Utopian Socialists is evident from the title: *An Essay on the Principle of Population, As It Affects the Future Improvements of Society; With Remarks on the Speculations of Mr. Godwin, M. Condorcet, and Other Writers.* (Malthus, 1798). But what did Malthus object to in Condorcet’s embodiment of Physiocratic and Smithian notions on food production? The answer centers firmly around Malthus’s beliefs regarding the limits of soil fertility and the role of technology in it. Recall Malthus thought that the productive qualities of land would increase by a set arithmetic rate every 25 years. Yet, the population would increase at least geometrically over the same period. Thus, his aforementioned conclusion that “the superior power of population [growth] cannot be checked without producing misery or vice….” (Malthus, 1798, p. 63). So, we arrive at the heart of our first argument regarding why Malthus seems to disagree with the work of Condorcet: Malthus was not a slave to the same "defunct economists" as Condorcet, at least regarding the rationality of man, fertility of the soil and the impact of technology on soil fecundity (Keynes, 1935, p. 383).

Our above discussion highlights how and why Condorcet appears to have embodied the Physiocratic notions of man's rationality, the importance of technological innovation, and nature's fertility. In this, Condorcet followed and built upon the foundations laid by Quesnay, Turgot, and Smith (Rothschild, 2001) But, "the early nineteenth century English economists deduced their doctrines, not from study of the works of their processors, but from the actual experience of England during the [Napoleonic] war" (Hollander, 1997, p. 739). Thus, Malthus did not share Condorcet's beliefs regarding man's rationality, the abundant fecundity of the soil, and the saving graces of agricultural technology (Hollander, 1997) (Condorcet, 1955). We will now examine the three main areas in which Malthus's views seemed to differ from those of Condorcet: the rationality of man, the fertility of the soil, and the limits of agricultural innovation.

First, regarding rationality, recall that Quesnay, Turgot, Smith, and Condorcet all believed man to be a comparatively rational creature (Vardi, 2012) (Spengler, 1942) (Rothschild, 2001) (Williams, 2004). Thus, a man would not run out and undo his wage increases via wanton propagation. However, that is precisely what Malthus stated in his second postulation "that the passion between the sexes is necessary and will remain nearly in its present state" (Malthus, 1798, p. 4). So, one possible reason Malthus doubted Condorcet's population predictions is that any food production improvement would cause workers to have yet more children (Malthus, 1798) (Hollander, 1997). But, in the interest of fairness, remember that starting in the second edition of his essay, Malthus allows for a third check on population, "the prudential check." The "prudential check" is a voluntary postponement of marriage during which a "period of celibacy" is practiced "till… the prospect of being able to maintain…children" exists. The adoption of the "prudential check" was primarily due to Malthus' interactions with William Godwin and his ideas of a rational individual (Malthus, 1803, pp. 598-599) (Winch, 1996). Thus, the inclusion of the "prudential check" represents an acknowledgment that man could be more logical than Malthus initially argued in his first edition of the population essay (Malthus, 1803, p. 599). Malthus also notes that "It cannot be doubted, that throughout Europe… a decided change has taken place in the operation of this prudential restraint" and that "at some future period…the more general prevalence of prudential habits with respect to marriage…" might increase and put the whole population question in a "different color" altogether (Malthus, 1803, pp. 386,596). Further, in saying that a future society might be able to better manage "the passion between the sexes," Malthus draws as close as he will ever get to agreeing with Condorcet's belief in a rational human being. For, as aforementioned, when a population increases, Condorcet holds that "the progress of reason will have kept pace with that of the sciences…" and people "will know that if they have a duty towards those who are not yet born, that duty is not to give them existence but to give them happiness; their aim should be to promote the general welfare of the human race, or of the society in which they live or of the family to which they belong, rather than foolishly to encumber the world with…beings" (Malthus, 1803, p. 26) (Condorcet, 1955, p. 189). This view of Condorcet is very similar to Malthus above notion of the "prudential check," save that Malthus does not allow for the use of contraceptives as Condorcet does (Malthus, 1803, p. 599) (Condorcet, 1955) (Malthus, 1798) (Heilbroner, 1997). However, Malthus does not seem to believe in the widespread adoption of the "prudential suggestion" any time soon (Malthus, 1803, p. 351). This is because "the preventive check to population… does not at present prevail much among the male part of society" (Malthus, 1803, p. 386). So, while Malthus came to allow that individuals might engage in the "prudential check," he does not seem to have believed that such a check would be employed to any meaningful degree, save perhaps in the future (Malthus, 1803, p. 599) (Malthus, 1826a) (Malthus, 1826b). Thus, in the sixth and last non-posthumous edition of the population essay, Malthus still held his second postulation that "The passion between the sexes has appeared in every age to be so nearly the same, that it may always be considered, in algebraic language, as a given quantity" (Malthus, 1826a, p. 529). Thus, despite the "prudential check," "the tendency to a virtuous attachment" continues to be "so strong that there is a constant effort towards an increase of population" (Malthus, 1803, p. 599) (Malthus, 1798, p. 9). Hence, Malthus's model remained one plagued with irrational beings, for whom increases in food led to unsustainable population growth (Malthus, 1826a) (Malthus, 1826b).

The second of the main areas in which Malthus's views seemed to differ from those of Condorcet regarded the earth's fecundity. A close examination of Condorcet's *Sketch* shows that irrational Malthusian reproduction does not doom society. As we have seen, Physiocratic, Smithian, and Condorcetian views all appear to hold that a population increase will likely feed itself (Condorcet, 1955) (Smith, 1937) (Vardi, 2012) (Spengler, 1942). Specifically, recall Condorcet believed that sufficient innovation could allow the land to become ever more fertile as the population increased (Condorcet, 1955). To see Condorcet's views on ever-increasing land fertility, consider figure 19. Figure 19 is a corn model fashioned after the one used by Malthus in 1823 (Glyn, 2006). The corn model has been adapted to fit Condorcetian views of land fertility. Figure 19 assumes a Malthusian doubling of population, combined with the previously discussed resultant Condorcetian minimally geometric (doubling) growth of food production (Malthus, 1798) (Condorcet, 1955). Additionally, assume that plots A through G are in cultivation prior to the population increase. So, in keeping with Condorcetian views, no new land is needed to be brought into cultivation. Instead, the existing farmland doubles its food production because of a doubling of the population. (Condorcet, 1955)

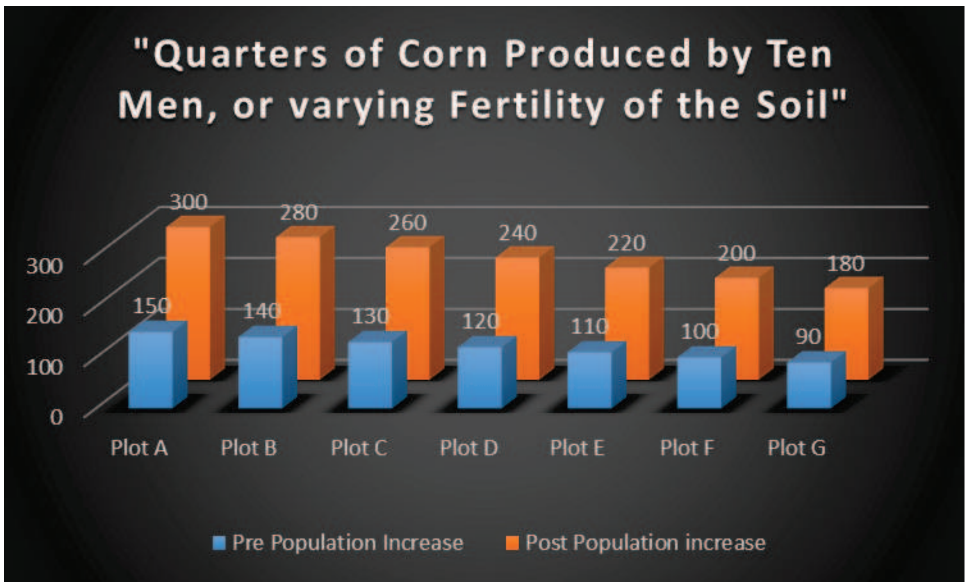

Figure 19. Condorcetian Corn Model of Geometric Land Fertility Increases

But for Malthus, land exhibited diminishing returns to fertility (Malthus, 1815). This was true even in the first edition of his population essay (Hollander, 1997). “Yet, the allowance that agriculture is subject to diminishing returns distinguishes Malthus from the Physiocrats” (Hollander, 1997, p. 371). More than this, Malthus held that “The best land would naturally be the first occupied” and thus already in cultivation (Malthus, 1817c, p. 6). Hence, any increase in population would require less and less fertile land to be brought into use. This is because “the most fertile lands of a country…are never found sufficient to supply the effective demand of an increasing population” (Malthus, 1815, p. 39). But this less fertile land would produce a smaller amount of food than the land already being tended (Malthus, 1815) (Hollander, 1997). To put the above graphically, consider figure 20. It employs Malthus's original figures from *The Measure of Value,* as reproduced on page 38 of Porta (1992). Note that “the 1823 pamphlet on *The Measure of Value”* represents an instance where Malthus “unambiguously” uses a corn model to illustrate his ideas regarding the diminishing fertility of the land (Glyn, 2006, p. 309). Figure 20 shows the

Malthusian notion that as the population increases geometrically, ever less fertile land is brought into use. Thus, Malthus's belief that the production of land could, at best, be arithmetic (Malthus, 1798).

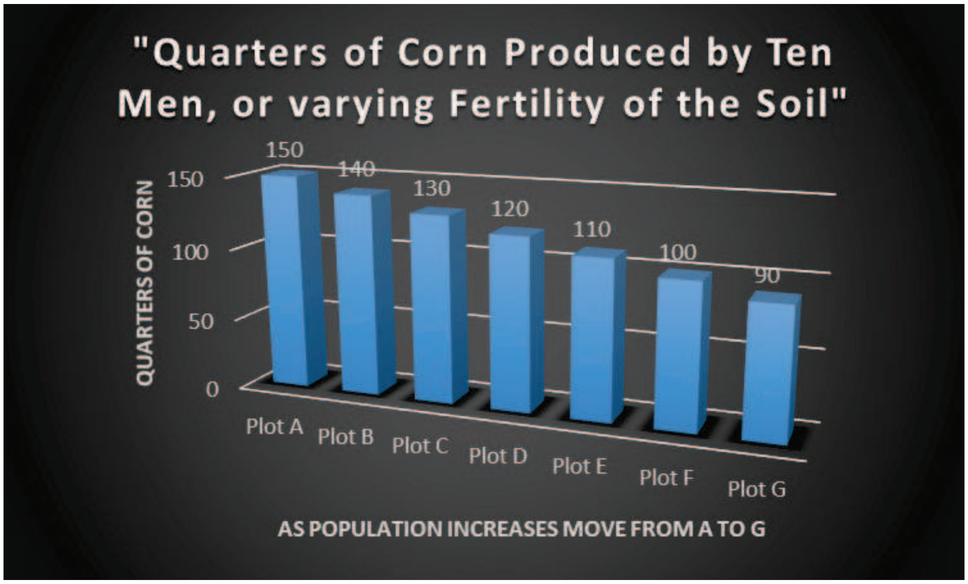

Figure 20. Malthusian Corn Model with Diminishing Land Fertility

The view of diminishing land fertility is why Malthus believed the best you can hope for is to keep increasing food production by a set amount every 25 years (Malthus, 1798). Thus, a second reason Malthus and Condorcet did not see eye to eye on population growth appears to have been differing beliefs on soil fertility.

A third possible reason for Malthus's objections to Condorcetian population theory is related to the above discussion of their respective views on the earth's fecundity. For Malthus, diminishing returns to soil fertility and its resultant arithmetic rate of food production was a situation he saw no way for society to innovate its way clear of. In the 5th edition of the population essay, "New technology is…unreservedly emphasized…with respect to future prospects" of food production (Hollander, 1997, p. 741). Yet, Malthus allowing for the possibility of a greater role of technology in food production does not equate to a belief in its ability to rescue a growing population from the ills of diminishing returns to the earth's fecundity (Malthus, 1817b) (Malthus, 1817c). Specifically, Malthus had this to say regarding the "systems of equality" of "Wallace, Condorcet and Godwin: "They see invention after invention in machinery brought forward, which is seemingly calculated…to abate the sum of human toil. Yet with these apparent means of giving plenty, leisure and happiness to all, they still see the labors of the great mass of society undiminished, and their condition, if not deteriorated, in no very striking and palpable manner improved" (Malthus, 1817b, pp. 271-272). Clearly, Malthus holds a dim view of Condorcet's belief in technologies ability to improve human conditions. In fact, Malthus points towards technology worsening the populational situation. Consider that if "new inventions take place in machinery, and new and great improvements are made in agriculture, it is quite obvious that… there must be… an unusual stimulus given to the population" (Malthus, 1817c, p. 168). Further, "if subsequently… the extension of the new machinery; and if the improvements in agriculture from any cause whatever cease to be progressive, it is as obvious that, just at the time when the stimulus to population has produced its greatest effect, the means of employing and supporting this population may…become deficient" (Malthus, 1817c, p. 168). So, while Condorcet sees an increase in population leading to a commensurate rise in innovation to feed it, Malthus actually assumes "that technology limits population" growth (Kremer, 1993, p. 681) (Condorcet, 1955) (Malthus, 1817c). Thus, a nation that relies on technological advances to feed their populations are doomed because "no ingenuity in machinery could save it from low profits and low wages, and their natural consequences, a check to population" (Malthus, 1817b, p. 407).

Yet such divergent views on the fertility of the earth, and technology's role in it, are hardly surprising when one considers the different conditions of British and French soil fecundity and agricultural innovation. As Arthur Young, the "foremost agricultural writer in England in the eighteenth century and… secretary of the Board of Agriculture in 1793," stated: "France is beyond all comparison more fruitful than the English dominions" when it came to matters of the soil (Sexauer, 1976, p. 494) (Young, 1769, p. 385). Young was not alone in noting the superior soil fertility enjoyed by 18th-century France over Britain. The French agricultural writer Leonce de Lavergne remarked, "How superior are the soil and climate of France." He then went on to detail all the environmental boons of rich dark soil, ample rain, and favorable weather, which made French arable land advantageous over Britain's (Lavergne, 1855, p. 6). But French soil was not just more fertile: there was also more of it. In fact, "France had nearly three times as much arable land" as Britain did when Condorcet and Malthus put their respective pens to paper (Sexauer, 1976, p. 494) (Condorcet, 1955) (Malthus, 1798).

But remarkably, France did not outproduce England by the above three-to-one ratio. The most reliable figures of the day hold that "for all cereals the ratio of average product per acre was about 28:18 in England compared to France" (Sexauer, 1976, p. 494). That is, for every 9 per acre bushels of cereal grain England produced, France generated 14. The reason France did not outproduce Britain by three-to-one was technological in nature.

England possessed much better advances in agricultural equipment and management than France did (Sexauer, 1976). In fact, France's agrarian disadvantages prompted Arthur Young to comment, "Heaven grant me patience while I see a country thus neglected- and forgive me the oaths I swear at the absence and ignorance of the possessors." (Young, 1792, p. 12) Such an opinion was the result of several forays to France that Mr. Young would take and subsequently write about in *Travels during the years 1787, 1788, and 1789, undertaken more particularly with a view of ascertaining the cultivation, wealth, resources, and national prosperity of the kingdom of France* (Young, 1792, p. 12). The French were also aware of England's technological advantage in agriculture. Duc de La Rochefoucauld-Lian-Court was a French gentleman farmer who visited England and later remarked that "At the end of the eighteenth century…English agriculture was further advanced than ours at the present day" (Lavergne, 1855).

Most importantly, Malthus read and cited Young's work in later editions of his population essay. Thus, Malthus was aware of Britain's dependence on agricultural technology to offset its inferior quantity and quality of soil (Malthus, 1817b). Specifically, Malthus wrote that "The soil of England will not produce much without dressing," while none "so fine a climate as France" exists for agrarian work (Malthus, 1817b, pp. 18, 253). Sexauer (1976) agreed, saying that "On average, the English soil was poorer and less productive [Than French] unless enriched by fertilizer" (Sexauer, 1976, p. 495). " Dr. Quesnay" was aware of the above differences in French vs. English soil fertility and quantity (Sexauer, 1976, p. 499). He was also conscious of the vital role of technology in agricultural productivity (Vardi, 2012) (Meek, 1962). Thus, via Condorcet's aforementioned close association with Physiocracy, it is highly likely that he too was aware of differences in quantity and quality of French vs. English soil, as well as the degree of technology employed for its cultivation (Rothschild, 2001) (Spengler, 1942) (Sexauer, 1976) (Williams, 2004). Hence, it seems both Malthus and Condorcet were influenced by their national backgrounds regarding the fecundity of soil and technology's role in it. The former was a man of an island nation obsessed with how to feed a population constantly on the brink of what its earth could support, and the latter a man of a verdant land far from tapping its agrarian potential (Hollander, 1997) (Heilbroner, 1999) (Sexauer, 1976) (Vardi, 2012).

But to better understand the implications of Malthus's rejection of the above-discussed views of Condorcet, and by extension Francois Quesnay, Anne Robert Jacques Turgot, and Adam Smith, on soil fertility and innovation, let us consider an agricultural Cobb Douglas style production function. We base ours on 18^{th}-century agricultural production function features, as detailed by Sexauer (1976) and adapted ala Mankiw (2016). Additionally, such a production function has been made compliant with the beliefs of Malthus and Condorcet. Regarding this function, we know that “Agricultural output is considered to be determined by five inputs: land, labor, capital, technology, and agricultural organization” (Sexauer, 1976, p. 493). But Malthus and “the classicalists…assume that output is produced by a production function involving land input and a *dose* of labour-cum-capital input” (Samuelson, 1978, pp. 1415-16). That is, the labor was believed to come equipped with the capital it needed to cultivate the land (Hollander, 1997, p. 24). Additionally, researchers consider 18th-century “agricultural organization” methods such as “The change from a fallow to a rotational system…” to be best “examined as a technological feature” (Sexauer, 1976, pp. 493,497). Thus, consider the following agricultural Cobb-Douglas production function.

$$QCP(Land, Labor) = A * Land^{f} * Labor^{(1-f)} \tag{1}$$

Where *QCP* are the quarters of corn produced, *A* “is a parameter greater than zero that measures the productivity of available technology,” *Land* is an input representing the number of plots of land cultivated, *Labor* is the number of men working on the land, *f* is the amount of corn produced which is attributable to the fertility of the soil, and *1-f* are the quarters of corn produced that are attributable to the productivity of labor (Mankiw, 2016, p. 59). Further, $0<f<1$ because, according to Malthus, land has diminishing marginal fertility (Malthus, 1798). Additionally, Condorcet’s model does not discuss what the fertility of newly cultivated soil will be. Instead, it focuses on increasing the fertility of existing farmland via innovation (Condorcet, 1955). Thus, adopting the Malthusian belief of diminishing returns to new land brought into cultivation does not violate Condorcet’s’ model, and therefore we will adopt such a stance. Further, let *A* be constant and equal to 1. This flows from Malthus's rejection of Condorcet’s ideas on technological growth from generation to generation (Malthus, 1798) (Condorcet, 1955). Now we are not concerned with labor’s impact on food production here. That would be beyond the scope of this paper and is not germane to the difference between Malthus and Condorcet on foil fertility and food production. Let us just note that labor equals “Ten men” per plot of land cultivated (Malthus, 1957, p. 39).

Figure 21 is the two-dimensional representation of our Malthusian corn production function discussed above. Note that the production of corn is a function of the number of plots of land in cultivation and the fixed amount of ten men’s labor per plot of land (Malthus, 1957). Figure 21 shows the diminishing returns to each extra plot of land brought into cultivation as the population increases. We can see that with each additional parcel of land cultivated, its marginal product decreases versus the previous land plot used. Thus, Malthus's preceding conclusion that "Subsistence increases only in an arithmetic ratio" (Malthus, 1798, pp. 4-5).

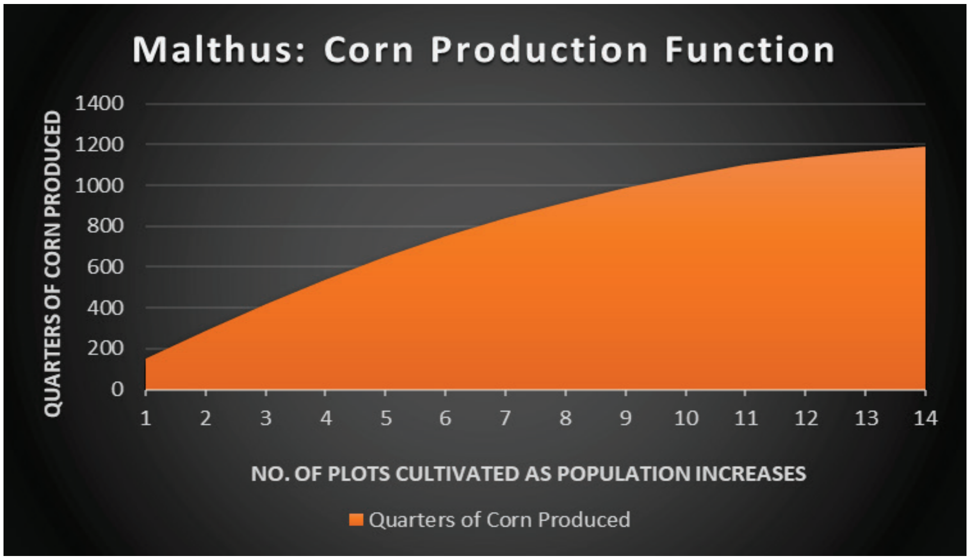

Figure 21. Malthusian Corn Production Function with Diminishing Land Fertility (*f*)

Now contrast figure 21 with Condorcet's belief that *A* would increase as the population increases (Condorcet, 1955). Specifically, if the population is growing at least geometrically, then we know that by Condorcet's six assumptions, so too does *A*. Recall *A* "measures the productivity of available technology" (Mankiw, 2016, p. 59). Thus, consider the Condorcetian case, where we conservatively assume *A* grows geometrically along with the population. Additionally, we retain the previous Malthusian logic. Doing so, we arrive at figure 22.

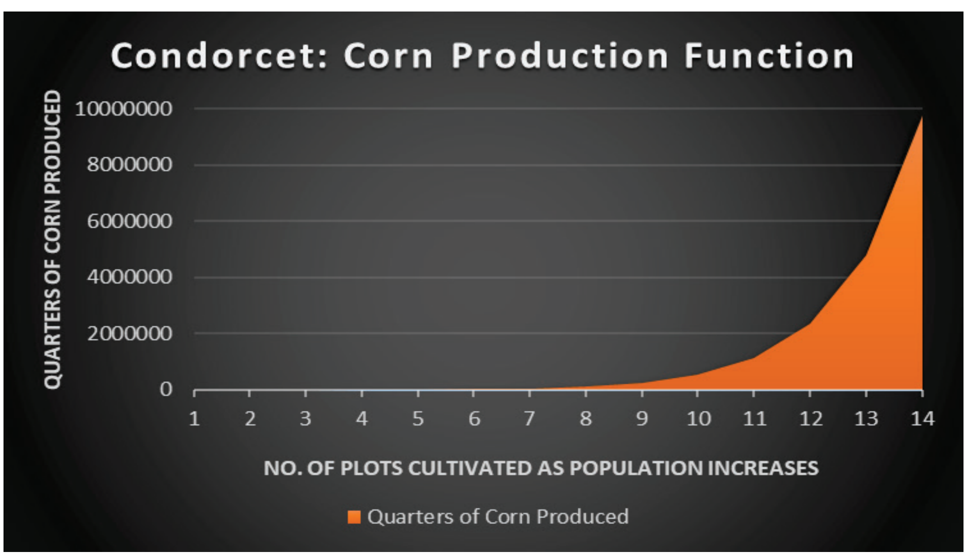

Figure 22. Condorcetian Corn Production Function with Increasing Innovation

Figure 22 presents the Condorcetian production function. Such a function yields the geometric food production increase, given the Malthusian geometric population increase. Basically, figure 22 is why the previous patterns of figure 16 and figure 18 occur. Note that the vertical axis values are larger in figure 22 than in figure 21 because the former exhibits geometric growth and the latter only arithmetic.

This concludes our consideration of the first reason that Malthus and Condorcet disagreed on population: they were not "slaves of" the same "defunct economist[s]" (Keynes, 1935, p. 383). We also looked at three implications of Malthus's rejection of the Physiocratic and Smithian ideals embodied in Condorcet's model of population growth. To summarize those implications, Malthus believed in irrational individuals with their "passion between the sexes," driving at least geometric population growth. Yet, such individuals lived in a world of technologically irredeemable diminishing returns to soil fertility. The results are seen in figure 17, figure 20, and figure 21. There we witnessed a geometrically growing population "checked" by "misery," "vice," and ever so slightly "prudence." This resulted from arithmetically increasing food production (Malthus, 1798, pp. 54,152) (Malthus, 1803, p. 599). But for Condorcet, soil possessed near-infinite fertility. This quality stems from a rational person's ability to innovate new and better means of cultivation. Finally, should such a rational individual have "ever exhausted" their ability to discover new and better food production methods, they would be willing and able to control the population's size for society's benefit (Condorcet, 1955). We have seen the results of such beliefs in figure 16, figure 19, and figure 22, where a geometrically increasing population led to matching geometric increases in food production.

A second possible reason for disagreement between Condorcet and Malthus on population may be that Condorcet was not around to defend his ideas. Therefore, Malthus was not forced to properly consider his differences with Condorcet and what such differences implied for the population essay. Recall that Condorcet died in the spring of 1794. Further, Condorcet's *Sketch* was not published posthumously until 1795 (Avery, 1997). But Malthus's first edition of the essay on population was printed in 1798. Thus, Malthus's contestations to Condorcet's ideas on population went unchallenged by their author (Malthus, 1798). This is important, considering the impact that other authors' defense of their ideas had on Malthus's work. Consider the aforementioned William Godwin, who lived from 1756 to 1836. He was a harsh critic of Malthus's essay on population and a vehement defender of his own beliefs (Philp, 2013). As a result of Godwin's efforts, his notions regarding private judgment and personal responsibility were given much more attention in Malthus's later editions of his essay. In fact, they served to influence Malthus's aforementioned inclusion of the "prudential check" on population growth (Malthus, 1803, p. 599) (Winch, 1996). Thus, William Godwin's ability to defend his ideas caused Malthus to more properly account for such notions (Winch, 1996). Further, Winch (1996) holds that "Condorcet would have been…a worthier opponent of Malthus than Godwin proved to be." Thus, if Godwin's defense of his tenets could make Malthus concede a new solution to population pressures, imagine what "a worthier opponent" might have been able to accomplish (Winch, 1996, p. 47). That is why Winch (1996) wishes "that Condorcet had lived long enough to answer Malthus criticisms of the tenth stage of" Condorcet's *Sketch* (Winch, 1996, p. 44).

A third reason Malthus disagreed with Condorcet's views may have been differing backgrounds. That is, bias may have been in play. For example, Malthus went against his father's wishes to become a reverend and not a surveyor (Pressman, 2014). Hence, it can be assumed that he was a firm believer in the tenets of his profession. This contrasts significantly with the views Condorcet held on religion and the church. He made numerous attacks on religion and the clergy. Condorcet talks openly in his *Sketch* about how priests and organized religion are significant causes of war, hatred, and bigotry (Condorcet, 1955) (Avery, 1997). Such views could hardly have escaped the attention of Reverend Malthus. Others certainly took note. Catholic Priest Lamennais accused Condorcet of the "crime of a "dogmatic "indifference" to religion" (Rothschild, 2001, pp. 37-38). Joseph de Maistre went further, saying Condorcet was "roaring against Christianity like a lion." (Rothschild, 2001, p. 197). But then, Malthus and Condorcet differed in other ways as well. For instance, their respective opinions on the poor and how they should be dealt with. Condorcet believed the only solution to poverty were state programs similar in nature to our notion of social security, Medicaid, and Medicare (Condorcet, 1955). However, Malthus held that any aid to the poor would serve only to incentivize them to have more children and thus undo any gains charity might seem to offer. Further, as the poor had more children, the increase in population would detrimentally raise food prices for all British people. In fact, this was one of Malthus's main criticisms regarding Condorcet's utopian world (Pressman, 2014). Another striking difference between the men was their national backgrounds of England and France, respectively. First, recall the previously discussed divergence these nations experienced in soil quantity, fertility, and agricultural technology. But more than this, England and France had hostile relations for over seven hundred years by the time either man put pen to paper (Jeffery, 2003). Further, recall that Condorcet, an aristocrat, supported the French Revolution and its ideals. But Britain militarily opposed such revolutionary notions (Jeffery, 2003) (Avery, 1997). In fact, one of the main motivations for post-revolutionary British economic writers was to disprove Physiocratic notions thought to have greatly inspired the French Revolution. Further, in Malthus' time, Condorcet was considered a Physiocrat, though today he is not (Williams, 2004). Particularly, Condorcet's *Sketch* was seen as "the final production of destructive philosophy…which could explain the phenomenon of the French Revolution" (Rothschild, 2001, p. 197). Thus, Malthus admitted to writing his essay on population to disparage "such men as…Condorcet." This was because the *Sketch* represented more than just the views of Condorcet, but instead those "of many of the literary men in France, at the beginning of the Revolution" (Malthus, 1798, pp. 3,54) (Rothschild, 2001, p. 197). All the above is not to say Condorcet and Malthus had no common ground. They were both avid supporters of a free market economy. They shared the belief that such a system was the most potent economic means to an ideal social outcome (Winch, 1996). Yet, it is not hard to see how differences of opinion, political background, and motivation might have overtly biased Malthus in his consideration of Condorcet's ideas.

Fourthly, Malthus may have disputed Condorcet's population predictions because he misunderstood some of Condorcet's meanings. Consider how Malthus reworded Condorcet's views on population growth. "M. Condorcet's picture of what may be expected to happen, when the number of men shall surpass their means of subsistence, is justly drawn. The oscillation which he describes will certainly take place, and will without doubt be a constantly subsisting cause of periodical misery. The only point in which I differ from M. Condorcet in this description is with regard to the period when it may be applied to the human race. M. Condorcet thinks that it cannot possibly be applicable but at an era extremely distant… it will appear, on the contrary, that the period when the number of men surpasses their means of easy subsistence has long since arrived; and that this necessary oscillation, this constantly subsisting cause of periodical misery, has existed in most countries ever since we have had any histories of mankind, and continues to exist at present" (Malthus, 1798, p. 48). But we have seen this is not what Condorcet's *Sketch* says will happen when "the number of men shall surpass their means of subsistence…." (Malthus, 1798, p. 48) (Condorcet, 1955). Instead, the assumptions of Condorcet's model indicate that there will be a resultant minimally geometric increase in food production, not an oscillation between happiness and misery (Condorcet, 1955). Thus, Malthus appears to have fundamentally misunderstood Condorcet's population model. Yet what Malthus is referencing above as Condorcet's views on population are merely an afterthought to the actual model. Such an afterthought considers the aforementioned possibility of man's ability to innovate being wholly exhausted, not the natural consequence of population growth, as Malthus seems to paint it (Condorcet, 1955) (Malthus, 1798).

But if Malthus misunderstood Condorcet's notions on population, the fault might not lie with a willful intent to do so. During Malthus's education, he was known to have taken "prizes for Latin and Greek and English Declamations" and had a fondness for "modern languages," especially "Italian literature" (Bonar, 1885, p. 406). However, "In French and German," Malthus, "wrote no translations…," and any proficiency in such languages is not evident (Bonar, 1885, p. 402). Now "It is sometimes said that" Thomas Robert Malthus's father "Daniel Malthus translated books from the French and German, and the *Dictionary of Anonymous and Pseudonymous English Literature* gives him as the translator of an essay on landscape, *Pual et Virginie,* and Goethe's *Die Liden des Jungen Werther*: but this is all myth" (Petersen, 1979, p. 22) (Bonar, 1885). Thus, it appears Thomas Robert Malthus would have to rely on the translations of others for his understanding of Condorcet. But the fact was that at the end of the 18th-century, translations were often of dubious quality (Bashford & Chaplin, 2016). Malthus's essay itself was a victim of alteration via translation. Consider that the French translation was missing four whole chapters of the original English text. Further, this very French adaption was later translated for the Spanish-speaking world. Such a rendering was undertaken by a "Portuguese man…and read by those whose native language was Spanish." Thus, much room existed for errors to creep into the "serially translated *essay*" (Bashford & Chaplin, 2016, p. 254). Condorcet's *Sketch* was no exception to the ill effects plaguing translations of the day. In fact, prior to the 1955 translation used here, "The only…English translation appeared anonymously in 1795." Further, the 1795 translation was "of poor quality and often inaccurate" (Condorcet, 1955, p. xiv). But this would have been the only English text available in Malthus time (Hollander, 1997). Thus, it is not hard to imagine many misunderstandings existing. This ties somewhat into our second point that Malthus's treatment of Condorcet's views on population might have been quite different had Condorcet survived past 1794 (Avery, 1997). Had Condorcet been around, he might have been able to set straight any misunderstandings that arose from faulty translations of his *Sketch*.

A fifth reason Malthus disagreed with Condorcet might be that he saw other parts of Condorcet's *Sketch* as excessively illogical. This may have made him overly suspect of the validity of Condorcet's notions on population. Consider book III of Malthus's essay. There he attacks Condorcet's idea of ever-increasing human lifespans. Condorcet says that the average human lifespan can increase due to improved medicine, exercise, food, and housing quality (Condorcet, 1955) (Malthus, 1798). As Condorcet summarizes it, "No-one can doubt that, as preventative medicine improves and food and housing become healthier, as a way of life is established that develops our physical powers by exercise…, the average length of human life will be increased and a better health and a stronger physical constitution will be ensured" (Condorcet, 1955, p. 199). But in Malthus's eyes, "The average duration of human life will…vary from healthy or unhealthy climates, from wholesome or unwholesome food, from virtuous or vicious manners, and other causes; but it may be fairly doubted whether there has been really the smallest perceptible advance in the natural duration of human life, since first we had any authentic history of man" (Malthus, 1798, pp. 49-50). Malthus goes on to call Condorcet's notion of increasing lifespans an "improbable and unfounded hypotheses… throwing us back again almost into the infancy of knowledge…." (Malthus, 1798, p. 53). As an aside, note that if man's lifespan grows ever longer, it follows that this could lead to greater population size. Thus, following Malthus's growth rates, this would cause even more misery had he accepted this notion as true (Malthus, 1798). However, Condorcet would not have been concerned because as average lifespans increased, so would an individual's ability to contribute to scientific understanding and innovations in food production (Condorcet, 1955). In a similar vein, both Malthus and Condorcet were Newtonians. Yet, Malthus held that Condorcet was "guilty of disregarding a fundamental methodological principle of any Newtonian science…[because] He had extrapolated from known causes to possible effects instead of confining himself to assigning possible causes to observable effects" (Winch, 1996, p. 49) (Avery, 1997, p. 7). Thus, Malthus's apparent disagreement with Condorcet's other notions and methodology may have led him to be overly dismissive of Condorcet's work on population growth.

Finally, Malthus might have differed with Condorcet's population ideas because he overlooked or misunderstood existing historical examples of agricultural innovations resulting from increasing populations. That is, he may not have suitably considered instances where Condorcet's ideas had historical precedence. Consider Northern Europe at the turn of the first millennium A.D. The Viking age was ending in Scandinavia (Harl, 2005). However, after over two centuries of raids that consumed Europe "like a devouring flame," the people of Scandinavia had significantly increased their wealth (Malthus, 1817a, p. 161) (Harl, 2005). Thus, as Malthus's model predicts, the Scandinavian population increased (Malthus, 1798) (Harl, 2005). However, this presented a population versus substance situation of truly Malthusian proportions. While the population had increased, food production had not kept up. This was because the clay soil of Scandinavia was not cultivatable by the ard (scratch plough) dominating agriculture in the rest of Europe at the time (Andersen, et al., 2016). However, an innovation was created, allowing "for better field drainage, access to the most fertile soils, and saving of peasant labor time…." Thus, "the heavy plough stimulated food production and, as a consequence, "population growth, specialization of function, urbanization, and the growth of leisure"" (Andersen, et al., 2016, p. 134). To cite a particular example, "the heavy plough accounts for more than 40% of the increase in urbanization experienced in the High Middle Ages in Denmark…" (Andersen, et al., 2016, p. 147). So, the heavy plough represents a historical event mirroring Condorcet's prediction. That is, a growing population leading to more efficient innovations in food production and thus supporting the new members of society (Andersen, et al., 2016) (Condorcet, 1955). There have been more recent examples of this phenomenon as well. Consider the green revolution and the potential of CRISPR genetics to yet again revolutionize food production (Specter, 2016) (Avery, 1997). But the Viking Age is an example that was studied by Malthus while writing various editions of his essay on population (Malthus, 1798) (Malthus, 1817a) (Malthus, 1826b) (Andersen, et al., 2016). Specifically, Malthus undertook a trip across Europe in 1799 to gather "supporting evidence for his Essay on Population in Sweden, Norway, Finland, and Russia…" (Burns, 2004). The information he gathered on his tour of Scandinavia would feature prominently in later editions of the population essay and prompt him to "have dwelt longer on the northern states of Europe… because[of]…a personal… acquaintance with these countries…" (Malthus, 1817a, p. 441). Thus, the heavy plough presents an example of Condorcetian population growth that would have been obtainable for study in Malthus's day and one to which he had great reason to be exposed. Yet Malthus does not mention this historical phenomenon in his later essay editions (Malthus, 1826a) (Malthus, 1826b). In fact, in his discussion of Viking-age Scandinavia, Malthus seems entirely oblivious to this agricultural event.

Further, Malthus describes Scandinavia's soil as "particularly ineligible" for agricultural activities (Malthus, 1817a, p. 165). But while he is correct that the "Clay soils [of Scandinavia] conferred no advantages prior to the introduction of the heavy plough;…once the heavy plough arrived, access to the fertile clay soils provided advantages in terms of productivity…" (Andersen, et al., 2016, p. 147). In fact, while Malthus comments that "in a general view of the subject, I cannot help considering this period of history as affording a very striking illustration of the principle of population," the "principle of population" which the Scandinavian high middle ages seem to have demonstrated was Condorcetian, not Malthusian (Malthus, 1817a, p. 168) (Andersen, et al., 2016) (Condorcet, 1955). Yet Malthus's seeming historical inaccuracies would hardly appear to have bothered him. As Malthus wrote, "It will be but of little consequence, if any of the facts or calculations which have been affirmed in the course of this chapter, should turn out to be false" (Malthus, 1803, p. 296). Such seeming inattention to historical detail prompted the biographer James Bonar to say of the Malthusian population essay, "its author is not careful to be full in his historical details" (Bonar, 1885, p. 153). But one potential implication of such a lack of attention to historical detail might be that Malthus was overly dismissive of Condorcet's ideas on population growth.

Who History Favored

Thus far, we have looked at the population models of Condorcet and Malthus, as well as a hybrid one that combines key features of both men. Additionally, we have considered reasons why the men may have disagreed with one another on population theory. However, it remains to consider if either man's views have been vindicated by history. The short answer is yes for both men.

But to understand how and why history has supported both Malthus and Condorcet's notions of population growth, we must first consider the matter of empirical observation. To begin with, we would have liked to empirically examine the historical accuracy of Malthus's population model and any changes resulting from the inclusion of Condorcet's assumptions. However, that is an expansive topic onto itself and thus better left as a field of future inquiry. That said, empirical investigations do exist on the subject of Malthusian population growth. Consider the work of Kremer (1993). It examines the empirical accuracy of a population model with endogenous technological growth. The model "assumes that each person's chance of inventing something is independent of population, so that total research output increases in proportion to population" (Kremer, 1993, p. 712). Further, "the model used…does not allow for either exhaustible natural resources or for an ultimate limit on the level of technology" (Kremer, 1993, p. 713). However, in adopting such assumptions, the author contradicts both Malthus and Condorcet. Malthus is refuted since the model holds that innovation potential is unlimited (Kremer, 1993) (Malthus, 1826a) (Malthus, 1826b). Condorcet is contradicted because "each person's chance of inventing something is independent of population" (Kremer, 1993, p. 712). But recall that Condorcet held the ability to innovate to be endogenous to population. As he said, "May not our parents…hand on to us also that part of the physical organization which determines the intellect, the power of the brain…? Investigation of the human faculties…seem to give substance to such conjecture…" (Condorcet, 1955, p. 201). However, the fact remains that with sufficient data, the model of Kremer (1993) could be adapted and employed to investigate the historical accuracy of both Condorcetian and Malthusian population models, as well as the hybrid model outlined above. This represents a verdant field for future investigation.

But historically, scholars seem to hold industrial and postindustrial periods as favoring Condorcet (Clark, 2007) (Heilbroner, 1999) (Hollander, 1997) (Winch, 1996). In fact, Malthus's own views on his dire predictions softened slightly over time. When Malthus anonymously put pen to paper in 1798, his outlook was bleak. But as "productivity increased during the Napoleonic Wars," we have seen how Malthus's essay editions became more hopeful (Ross, 1998, p. 15) (Malthus, 1798) (Malthus, 1803) (Malthus, 1817a; Malthus, 1817b; Malthus, 1817c) (Malthus, 1826a; Malthus, 1826b). In fact, "While it was rational for him [Malthus] on the basis of recent history [late 18th-century] to… fear the effects of rapid population growth, that pattern did not continue" (Hollander, 1997, p. 785). Thus, E.A. Wrigley "maintains…Malthus failed to appreciate future changes already underway in his own time" (Hollander, 1997, p. 784). Specifically, he does not seem to have properly grasped the world-altering impacts of the industrial revolution on previous population growth trends (Clark, 2007).

Firstly, the industrial revolution unleashed a wave of global innovation, the likes of which the world had never seen. From the "spinning jenny" of 1764 to steam-powered boats in 1803, trains in 1814, and the telegraph in 1832, technological advancement was to permeate the very air of Malthus's time (Petersen, 1979, p. 1). Such developments would fundamentally alter the world as Malthus knew it. Particularly those "advances" which "constituted new modes of agriculture…" (Petersen, 1979, p. 2). In fact, "Malthus had grossly underestimated the future improvements in agricultural techniques…," begun in his own time (Petersen, 1979, p. 62). This occurred because the world was no longer a realm where Malthus could safely assume that "we have no right to conclude that they will ever cease to be what they now are…," regarding anything, let alone his postulations on population (Malthus, 1798, pp. 4-5).

Secondly, the vast increases in innovation impacted population in more ways than simply improved agricultural methods to feed society. While the first pages of the book of industrial revolution were dark for humanity, that outlook changed dramatically over time (Heilbroner, 1999). Notably, improvements in "medicine and sanitation…started a remarkable reduction in mortality associated with modern times" (Petersen, 1979, p. 2). An especially "important factor in the fall of the death rate was the decline of infant mortality…," brought about by the above improvements. But "these facts are of significance because they bear directly upon the population controversy of the 1830s and 1840s. Moreover, they serve to remind us that Malthus himself never clearly grasped the nature of the "population explosion," which he had set out to analyze." For while Malthus "seems to have been aware of the decline in the death rate," he "underestimated its significance; in addition, he virtually ignored any factors influencing the mortality rate, other than shortage of food" (Blaug, 1958, p. 103)

Thirdly, industrialization led to urbanization, and urbanization turned large families from assets to liabilities (Sexauer, 1976) (Petersen, 1979) (Heilbroner, 1999). This would have a significant impact on the size of families. Consider that "In 1860, in Great Britain, about 60 percent of all married couples had families of four or more. By 1925 only one couple in five had a family that size. Conversely, the number of families with only one or two children increased over the same time span, from 10 percent of the total to over half" (Heilbroner, 1999, p. 93). The increased use of birth control and family planning has featured heavily in the above trend of globally decreasing family size. In fact, "As England and the West enjoyed a gradually widening affluence, the poor not only ate and clothed themselves better, but they also learned how to limit their offspring like the wealthier classes" (Heilbroner, 1999, p. 93). Further, Kremer (1993) empirically showed that "Per capita income gradually increases with the growth rate of technology, and eventually this causes population growth to slow" (Kremer, 1993, p. 712). This is found to be globally true, even in ancient times (Kremer, 1993). Thus, the trend of industrialization to urbanization to shrinking family sizes has been repeating itself worldwide (Heilbroner, 1999) (Ross, 1998). But this is nothing if not Condorcet's belief that as society matures, its members will come to "know that if they have a duty towards those who are not yet born, that duty is not to give them existence but to give them happiness; their aim should be to promote the general welfare of the human race, or of the society in which they live or of the family to which they belong, rather than foolishly to encumber the world with…beings" (Condorcet, 1955, p. 189).

Finally, the above reasons why our global society seems to have largely avoided Malthus's predictions on population are explanations that Condorcet gives in his *Sketch*. That is, humanity's demonstrated abilities to innovate new and ever more productive means of food production, advances in medicine, sanitation, and family planning. Condorcet was even correct in his aforementioned belief that the average human lifespan would increase as a result of the above improvements. (Condorcet, 1955) (Ross, 1998) (Winch, 1996) (Clark, 2007).

But recall that we began by naming Condorcet as the winner of the population debate for industrial and postindustrial periods. This is because Malthus's model, with its predictions of humanity "condemned to a perpetual oscillation between happiness and misery," "matches the empirical evidence for [the] preindustrial world" rather well (Malthus, 1798, p. 1) (Clark, 2007, p. 5). There were instances of Condorcetian population growth, like the High Middle Ages of Scandinavia. Still, by and large, "the average person in 1800 was no better off than his or her ancestors of the Paleolithic or Neolithic" (Clark, 2007) (Andersen, et al., 2016). So "When Thomas Malthus laid out this vision in 1798, he was dead on about the…past history of humankind, though the Industrial Revolution was about to prove him wrong about the future" (Clark, 2014). But recall the title of Malthus's first edition was *An Essay on the Principle of Population, As It Affects the Future Improvements of Society; With Remarks on the Speculations of Mr. Godwin, M. Condorcet, and Other Writers* (Malthus, 1798, p. 1). Thus, the Malthusian population model suiting the past well but not applying to "the Future Improvements of Society" is tantamount to a faulty prognosis. Yet, this might be an oversimplification. It is perhaps more accurate to say that global industrialization has thus far proved Malthus wrong. For "We must not forget that Malthus was right in claiming that population growth…inherently has the *capability of* swamping increases in agricultural productivity" (Heilbroner, 1999, p. 92). We must be especially mindful of such possibilities in a world enduring the unique effects of climate change and pandemics such as covid 19 (Mgbemene, et al., 2016) (Joi, 2020).

While we discussed several reasons that the industrialized world has "escaped the Malthusian trap…," "the crucial factor was the rate of technological advance" (Winch, 1996, p. 49) (Clark, 2007, p. 5). In fact, "the typical rate of technological advance before 1800 was well below 0.05 percent per year, about a thirtieth of the modern rate" (Clark, 2007, p. 5). But increasing the rate of innovation by thirteen times over has come at a price. That cost is climate change. For while "Industrialization has always seemed…key to wealth and better living…, it has been shown that…it affects environment and ultimately contributes to climate change." Yet, climate change brings with it agriculturally impactful phenomena like "higher temperatures" and other "extreme weather conditions" (Mgbemene, et al., 2016, p. 301). That said, the net global results of climate change on arable land and agricultural food production can be hard to ascertain. This is mainly because climate change affects different parts of the world differently. For example, consider the impact of climate change on the amount of available arable land. "Regions characterized by relatively high latitudes such as Russia, China, and the US may expect an increase of total arable land by 37–67%, 22–36%, and 4–17%, respectively, while tropical and sub-tropical regions may suffer different levels of lost arable land. For example, South America may lose 1–21% of its arable land area, Africa 1–18%, Europe11–17%, and India 2–4%" (Zhang & Cai, 2011, p. 1). However, the "Net arable land [available] around the end of the 21st century…is projected to decline by 2–9% globally" (Zhang & Cai, 2011, p. 8).

But what of the potential impacts of climate change on agricultural productivity? The latest estimates hold that climate change has slowed down the growth rate of agricultural total factor productivity by "about 21% since 1961…. The effect is substantially more severe (a reduction of ~26–34%) in warmer regions such as Africa and Latin America and the Caribbean" (Ortiz-Bobea, et al., 2021, p. 306). But while the growth rate of agricultural total factor productivity has slowed, it is still positive in most of the world. In fact, the average nation has seen a 76 percent increase in agricultural total factor productivity since 1961 (Ortiz-Bobea, et al., 2021).

So, while climate change is reducing the amount of arable land, the average nation is still increasing its agricultural total factor productivity. Further, "on average, global food supply currently exceeds demand by about 20 per cent…" (Parry, 2019, p. 153). However, "While averaged *global* food supplies may not be seriously threatened [by climate change]…serious regional and year to year food shortages may result, with particular impacts on vulnerable groups" (Parry, 2019, p. 153). As we have seen, perhaps no region is at more risk than Africa. But if a population crisis is to unfold there, it will likely have more to do with unfavorable political and institutional frameworks than the Malthusian population model (Ross, 1998). Generally, it seems that climate change has yet to drive us back from our Condorcetian "future" into the hands of the "Malthusian Trap" (Winch, 1996, p. 49) (Clark, 2014) (Parry, 2019). If the fact that "average, global food supply currently exceeds demand by about 20 per cent…" was not enough evidence of this, consider that in opposition to Malthus's predictions for such a situation, the total fertility rate continues to decline (Parry, 2019, p. 153) (Roser, 2020a). In fact, "Up to 1965 the average woman in the world had more than 5 children. Since then, we have seen an unprecedented change. The number has halved. Globally, the average per woman is now below 2.5 children" (Roser, 2020a).

But climate change also threatens our Condorcetian world via disease. In fact, "Most of the recent sporadic outbreaks of infectious diseases can be attributed to climate change indicators such as rising temperatures and increased humidity" (Mgbemene, et al., 2016, p. 314). Particularly, "Climate change gives rise to environmental conditions that can have far reaching effects on human health and existence. Direct effects are diseases and deaths as a result of extreme weather events like heat, flooding, mud slides, storms and hurricanes. Indirect effects…result from changes in the ecosystem, such as conditions that facilitate infectious diseases…." (Mgbemene, et al., 2016, p.

309). Making matters worse, those same parts of the world that climate change hits hardest agriculturally bear the brunt of its impact via diseases. Examples include Africa, South America, parts of Asia, and the Caribbean (Mgbemene, et al., 2016). Unfortunately, these areas of the world were plagued with higher disease and mortality rates even in Malthus time (Acemoglu, et al., 2001). Further, the past reasons for the increased rate of disease in those areas were essentially the same, high "temperature and humidity" (Acemoglu, et al., 2001, p. 1382).

In addition to direct climate conditions, "Throughout history and prehistory trade and economic growth," such as occurs with global industrialization, "have always entailed serious population health challenges" (Szreter, 2004, p. 75) (Clark, 2007). This is because the very same industrialization that delivered humanity from the "Malthusian Trap" has also led to increased urbanization, international trade, and tourism (Winch, 1996, p. 49) (Szreter, 2004) (Gierczak, 2011). The result has been more "regular social interaction between populations previously not exposed to each other's disease ecology, and…the increasingly dense permanent settlement of populations." Further, "Both of these relationships have always been understood to be negative, in terms of the health of the populations exposed" (Szreter, 2004, p. 76).

There is perhaps no better example of the potential disease-inducing risks of industrialization than the Covid 19 pandemic. Covid 19 spread across the globe in record time. The first cases were reported in Wuhan in December 2019. But a mere four months later, "Deeply concerned both by the alarming levels of spread and severity…WHO made the assessment that COVID-19 can be characterized as a pandemic" (WHO, 2020). Since its appearance, Covid 19 has decreased the average global lifespan of individuals by 1.26 years. Some nations have witnessed as much as a 2.5-year decrease in average lifespans. Thus, Covid 19 is the single largest cause of decreased average global lifespans since World War II (Heuveline & Tzen, 2021). Covid 19's impact on the global average lifespan has far outpaced any other recent cause, disease-related or not (Heuveline & Tzen, 2021). In fact, Covid 19 has currently claimed the lives of almost 6.5 million souls worldwide (WHO, 2022). In a world of 7.9 billion people, that means Covid 19 has killed roughly 0.08 percent of the global population (Roser, et al., 2022a). However, the impact of Covid 19 pales in comparison to the previous global pandemic, known as the Spanish flu. The Spanish flu was responsible for the loss of "an estimated 40 million people" across the globe (Taubenberger, 2006, p. 86). Further, the global population at the time was roughly 1.8 billion. Thus, the Spanish flu claimed the lives of a staggering 2.2 percent of the world's population. "The impact was so profound as to depress average age life expectancy in the U. S by more than ten years" (Taubenberger, 2006, p. 91). But America was not alone in such a depression of average life expectancy. It was a global phenomenon. In fact, the Spanish flu was "the largest influenza pandemic in history" (Roser, 2020b).

Yet, despite the above temporary decreases in life expectancy, the average lifespan of an individual continues to climb. Consider that "Life expectancy was no higher in 1800 than for hunter-gatherers: thirty to thirty-five" (Clark, 2007, p. 1). But as of 2022, the global average life expectancy at birth is 73 years (WHO, 2022). That number is projected to be roughly 83 years by 2100 (Letzing, 2021). Additionally, recall that early in the industrial revolution, an "important factor in the fall of the death rate was the decline of infant mortality…" owing to better innovations in medicine and sanitation (Blaug, 1958, p. 103). Infant and child mortality rate reduction is still an essential part of the picture of increasing global life expectancy. In fact, "from 1800 to 1950 global [child] mortality has halved from around 43% to 22.5%." Further, since 1950 that rate has been reduced from 22.5% to under 4% (Roser, et al., 2020). However, decreasing infant and child mortality is only half of the picture regarding why global average life expectancy is predicted to reach 83 years in 2100 (Letzing, 2021). The other half is the increased longevity of those surviving past their fifth birthday. Specifically, the global life expectancy of someone making it to 5 years old has gone from 48.2 years old in 1841 to 82.2 years old in 2022. That is an astonishing 70.5% increase in the average time one can expect to live upon reaching age (Roser, et al., 2022b).

So notwithstanding climate change and pandemics like Covid 19, we have seen persistent increases in agricultural production, decreasing total fertility rates, and increasing average lifespans. But this is precisely what Condorcet predicted in 1793 (Condorcet, 1955). As Condorcet summarizes it, "No-one can doubt that, as preventative medicine improves and food and housing become healthier, as a way of life is established that develops our physical powers by exercise…, the average length of human life will be increased and a better health and a stronger physical constitution will be ensured." Further, "The improvements of medical practice, which will become more efficacious with the progress of reason and of the social order, will mean the end of infectious and hereditary diseases and illness brought on by climate, food, or working conditions." Additionally, "It is reasonable to hope that all other diseases may likewise disappear as their distant causes are discovered." Thus "Would it be absurd then to suppose…that the day will come when death will be due only to extraordinary accidents or to the decay of the vital forces…? Certainly man will not become immortal, but will not the interval between the first breath that he draws and the time when in the natural course of events without disease or accident, he expires, increase indefinitely?" Condorcet goes on to say that by indefinitely increasing average life spans, he means increasing towards a then unknown natural limit to human life (Condorcet, 1955, pp. 199-200). The above Condorcetian predictions are exactly why Donald Winch notes that Condorcet "predicted exactly those methods by which mankind…escaped the Malthusian trap…" (Winch, 1996, p. 49). As an aside, note that current research puts the limit of human life somewhere between 120-150 years and that this "signifies a fundamental or absolute limit of human lifespan" (Pyrkov, et al., 2021, p. 2765). Contrast the above with Malthus's world, where humanity could expect an average life of 30-35 years, filled with never-ending "misery" and "vice" because that is the way it had been and ever would be (Malthus, 1798, p. 78). Thus, it thankfully appears that Condorcet's view of the future seems to be more in line with current reality and future projections (Winch, 1996) (Clark, 2007).

Perhaps the above is best summarized with the following figure of world population growth from 1000 to 2028. This data comes from the work of Roser, et al. (2022a). Now, consider figure 23.

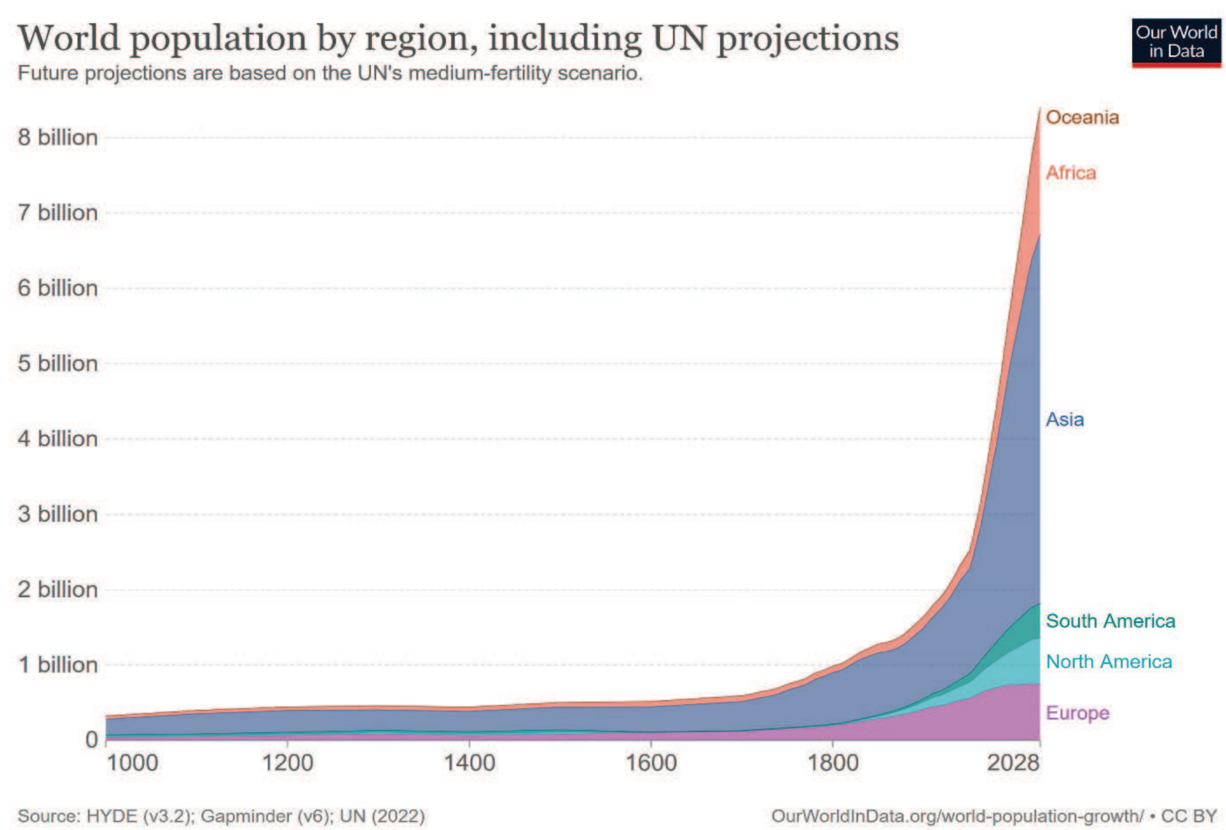

Figure 23. World Population Growth by Region (Roser, et al., 2022a)

We can see that up through 1800, global population growth appears to have behaved as Malthus predicted. That is, the pattern is very similar to that of the arithmetic food growth seen in figure 17. However, after 1800 population growth appears much more in keeping with Condorcet's predictions, as represented in figure 16. Thus it seems that Clark (2014) is justified in this aforementioned statement that "When Thomas Malthus laid out this vision in 1798, he was dead on about the…past history of humankind, though the Industrial Revolution was about to prove him wrong about the future."

Conclusion

Looking at Condorcet's *Sketch*, we have seen six assumptions implying that as the population grows, it leads to innovations capable of supporting such growth (Condorcet, 1955). Further, we have witnessed how Malthus's model predicts population increases that result in "misery" and "vice." We also created a hybrid model to attempt to account for the implications of Condorcet's views on population growth and innovation in an otherwise Malthusian population model. We saw that this model had an outcome largely free of "misery" and "vice" (Malthus, 1798, p. 78).

We continued by looking at possible reasons why Malthus disagreed with Condorcet's views on population and the implications for Malthus's model. These reasons included; Condorcet and Malthus being influenced by different economic ideologies of soil fertility and the limits of agricultural innovation, Condorcet having died before Malthus published his work, potential bias of Malthus towards Condorcet's work, possible misunderstanding of Condorcet's writings by Malthus, Malthus's disbelief in other aspects of Condorcet's writing leading him to disagree with Condorcet's notions on population growth, and Malthus's seeming failure to look closely enough at existing historical examples of Condorcetian population growth.

Finally, we briefly considered whose population growth ideas were favored by historical research and data. The short answer was that pre-1800 Malthus population predictions proved more accurate. However, post-1800, Condorcet's prognostications seem closer to the mark (Clark, 2014) (Winch, 1996). Further, we discussed how and why the industrial and post-industrial revolution world has been one that seems to conform to Condorcetian expectations on population. However, considering that Malthus and Condorcet's disagreements concerned "The Future Improvements of Society," it would seem that Condorcet got the better of the argument (Malthus, 1798, p. 1).

In closing, let us note the words of Malthus: “I have read some of the speculations on the perfectibility of man and society with great pleasure. I have been warmed and delighted with the enchanting picture they hold forth. I ardently wish for such happy improvements” (Malthus, 1798, p. 33). Perhaps then Malthus would not begrudge us a world in which it seems that Condorcet “predicted exactly those methods by which mankind…escaped the Malthusian trap….” (Winch, 1996, p. 49). Yet conceivably, the very existence of Malthus’s dire warnings regarding population growth may be responsible for steering humanity toward the arms of a Condorcetian reality. For as Malthus said, “I had much rather believe that some real and deeply-seated difficulty existed, the constant struggle with which was calculated to rouse the natural inactivity of man, to call forth faculties, and invigorate and improve his mind…than that nearly all the evils of life might with the most perfect facility be removed…”, because “If…I could not only believe that a fundamental and very extraordinary improvement in human society was possible, but feel a firm confidence that it would take place, I should undoubtedly be grieved to find, that I had overlooked some cause, the operation of which would at once blast my hopes” (Malthus, 1817c, p. 380).

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APPENDICES

Appendix I: Housing Data Discussion

Our original housing records came in four separate data sets. Each dataset included the housing characteristics and various sale price measures for all single-family homes sold in a two-fiscal year period. The first data set covered July 1st, 2012, through June 30th, 2014. Each subsequent dataset began July 1st and ended June 30th, two years later. Thus, our four data sets covered a combined period of July 1st, 2012, through June 30th, 2020. The first task in making such data usable was to match all the shared data information between data sets. This involved meeting with the Denver County Assessor numerous times to establish each data column's contents and how it related to data columns of other fiscal years (Erffmeyer, 2021).

Following the guidance of the Denver County Assessors, we constructed a list of information common to all data sets. We then expunged all records not common among the data sets. Our next task was to create a list of universal data column identifiers. This was needed because the original Denver County Assessor's data often changed data titles between years. For instance, the total square footage of the living area for a home was titled imp area in one data set and liv area in another. Next, certain columns of data had condensed information. For instance, the data sets from 2012-2018 had the neighborhood code and neighborhood name in separate columns. Yet, the 2018-2020 data had them combined in one column. Thus, we had to separate information in certain columns to match previous data sets.

The 2018-2020 data was unique in another way: it had the day of home sale listed. From 2012-2018 the Denver County Assessor recorded all homes as being sold on the first day of the month. However, after 2018 the actual day of the sale was recorded. Thus, we changed all days of purchase to the first of their respective month of sale. This allowed us to merge all data by date. Finally, we organized and cleaned the combined housing characteristics and sale value data. This involved changing some data types from integer to date, sorting data, and establishing indices. Next, we removed all observations where the sale was land-only. Sometimes, a rundown property is sold for the value of its land. In this case, the home is demolished after purchase to make room for new developments. Including such land value sales would distort the impact of housing characteristics on home value.

There were also several observations whose sales had been calculated by agents outside the Denver County Assessor's office. We removed those observations. The above resulted in a total of 3 observations being removed.

Additionally, we needed to create a variable for the age of the home at the time of its sale (Englund, et al., 1998). Many authors have shown that the age of a home is a vital characteristic to account for (Case, et al., 1991) (Case & Quigley, 1991) (Hill, et al., 1997) (Oust, et al., 2020). Thus, we created a variable representing the age of the home at its time of sale. This was done by extracting the year from the date a house was sold. We then solved the following equation to obtain the age of the home at its time of sale.

$$AGE\ SOLD = year\ sold - year\ built$$

There were 19 homes sold in the year before their construction was completed (Erffmeyer, 2021). Thus, we dropped those observations to prevent negative age at the time of sale. Now we could have taken the absolute value of the year sold minus the year built. However, we wished to prevent and loss of information this might lead to. The 3,243 homes sold in their first year of existence were of further concern. This resulted in zero values for such homes. However, a year sold of zero is not realistic or accurate, as these homes sold in their first year, not their zeroth year. Thus, the 3,243 homes sold in the year they were built were assigned an age sold of 1. However, it made more sense to use the effective year of construction for previously discussed reasons. That is, it accounts for renovations as well as age. Thus, we did not utilize the age sold in our final analysis. However, it is employed in a robustness check in appendix vi: age at sale vs. effective year built.

Having organized and altered our data, we came to the matter of cleaning it. Towards such ends, we consulted the Denver County Assessors to resolve null values for the number of half bathrooms. Here the nulls were equivalent to zero and adjusted as such (Erffmeyer, 2021). We then had to deal with 12 zero values for the lot size of a home. For obvious reasons, this is not zero. We contacted the Denver County Assessors, and they were able to obtain the proper values and update their systems with them. We then updated our data with the correct lot sizes for each of the 12 homes (Erffmeyer, 2021). There were also 16 homes missing their number of stories. Again, we contacted the Denver County Assessors, who obtained, shared, and updated their system with the correct information (Erffmeyer, 2021). Additionally, there were 8 homes with either null or zero values for the number of full baths. Again, we reached out to the Denver County assessors, and they determined the proper values for those homes. Again, the correct values were shared, which we used to update our data. (Erffmeyer, 2021). We then came to the matter of organizing the effective year of a home's construction. Houses existed with a zero value for the effective year of construction. This indicated that no value-increasing renovations had occurred. Thus, the Denver Cunty Assessors informed us that their procedure in such a case is to update all zero values with the actual year built for those homes (Erffmeyer, 2021). This is what we did.

Appendix II: Marijuana Data Discussion

First, we combined the 3 data sources discussed in our data section. We thus obtained one comprehensive dataset of total marijuana revenue generated in Denver County. Such records covered our sample period of January 1st, 2014, to February 29th, 2020. Secondly, we lagged the date by one month for all Colorado department of revenue data files. This was done because all files obtained from the Colorado Department of Revenue were one month behind the actual date the revenue was generated. For example, the file dated February 2014 contains the tax revenue collected for January 2014. This is because the state does not know the total marijuana tax revenue until the next month (Colorado Department of Revenue, 2020). Thirdly, we imported each month's medicinal tax revenue. Fourthly, we introduced each month's recreational marijuana tax revenue. Fifthly, we obtained the total monthly medicinal marijuana revenue by solving the following equation.

$$x_m = y_m / t_m$$

where x_m is the total marijuana revenue generated from sales in month m, y_m is the total monthly marijuana tax revenue in month m, and t_m is the appropriate tax rate for month m. For example, consider January 2014 from our medicinal marijuana data source. There, $y_{january\ 2014} = \$442{,}941$, and $t_{january\ 2014} = 0.029$. Thus

$$x_{january\ 2014} = \frac{\$442{,}941}{0.029} = \$15{,}273{,}827.59$$

The results of such work were recorded as our total monthly medicinal marijuana revenue. Sixthly, we used the above approach to obtain total recreational marijuana revenue for Denver County in any given month. That is, up to June 30th, 2017. After that date, we had to account for the change in data reporting used by the Colorado Department of Revenue. Specifically, after June 30th, 2017, our data on tax revenue represented 90% of the total tax revenue generated. In addition, the tax rate had changed to the 15% Recreational Marijuana State Sales Tax. Hence, to get the total recreational marijuana sold after June 30th, 2017, we solved the following equation for each month in our sample period. Consider:

$$x_m = y_m/[(p_m)(t_m)]$$

where x_m is the total marijuana revenue generated from sales in month m, y_m is the total monthly marijuana tax revenue in month m, p_m is the percentage of the total tax revenue generated in month m, and t_m is the appropriate tax rate in month m. Consider August 2017, where $y_{August\ 2017} = \$4{,}548{,}655$, $p_m = 0.9$ and $t_m = 0.15$. Thus

$$x_{August\ 2017} = \frac{\$4548655}{[(0.9)(0.15)]} = \$33{,}693{,}740.74.$$

Our seventh step was simplifying our figures by putting them in terms of millions. We did this by dividing the total medicinal and recreational marijuana by one million each. This was done for ease of computation and comprehension. Finally, we removed all data after February 29th, 2020. Such datasets were then merged with the primary marijuana dataset.

Appendix III: Cluster Robust Errors

Here we lay out the motivation for clustered errors. Additionally, we shall investigate several alternative approaches for what variable or variables we are best suited to cluster on. We begin with the observation by Stock & Watson (2007) that "a key feature of time series data is that observations falling close to each other in time are not independent but rather tend to be correlated with each other" (Stock & Watson, 2007, p. 129). Such a situation is known as "autocorrelation" or "serial autocorrelation" (Gujarati, et al., 2009, p. 437). Yet, we employ several data records which are originally time series in nature. Most importantly, our marijuana tax revenue data is initially time series data. We are intentionally using the term initially, for once the data has been merged, our resultant dataset is cross-sectional. But this does not alter the likely relationship between observations of marijuana revenue. The amount of marijuana revenue generated this month is likely, related to the marijuana revenue generated in the past month. Consider research from Denver County, which finds "between 20.3-26.2 percent of the state's marijuana consumers report near-daily use of marijuana" (Orens, et al., 2018). Thus, a relationship between the revenue generated between months is probable. However, as with other time series serial correlations, such a relationship will likely diminish in strength over time (Cameron & Miller, 2015). That is, this month's marijuana revenue is unlikely to be as related to the revenue from three months ago as that of a month past. Additionally, it is not only marijuana revenue that is initially time series in nature. Consider the robustness data on the average wage, net migration trends, and the total number of people employed. By Stock & Watson (2007), and similar logic to marijuana revenue, it is possible that observations in one month are related to those in previous and subsequent months. Further, by construction, we know that our net migration data suffers from serial autocorrelation. See appendix v: monthly net migration data. Hence, we almost certainly have serial autocorrelation issues to account for.

But it is also probable that our final cross-sectional data has some degree of "spatial autocorrelation" as well (Stock & Watson, 2007, p. 436). Consider adjoining neighborhoods. It is reasonable to suspect that homes sold in contiguous neighborhoods could be related. For example, crime might affect multiple adjacent neighborhoods (Erffmeyer, 2021).

Thus, we must address both potential serial and spatial autocorrelation concerns. Consider that "Failure to control for error correlation can lead to very misleadingly small standard errors, and consequent misleadingly narrow confidence intervals, large t-statistics, and low p-values" (Cameron & Miller, 2015, p. 318). Thus, such situations can lead to inaccurate interpretations of statistical significance. In fact, "It is not unusual to have applications where standard errors that control for within-cluster correlation are several times larger than default standard errors that ignore such correlation" (Cameron & Miller, 2015, p. 318). In short, if we fail to account for our almost certain serial and possible spatial autocorrelation, we are biasing our results in favor of rejecting our null hypothesis. That is, potentially biasing our results towards over-acceptance of a statistically significant association between marijuana revenue and home prices in Denver County.

The best way to overcome potential serial and spatial autocorrelation is to employ both fixed effects and cluster robust errors (Cameron & Miller, 2015). The first step in this process is to determine if clustering of errors is required. This might seem a straightforward proposition: if one has serial either/or spatial autocorrelation, one employs cluster robust errors. However, there is another way to deal with the serial autocorrelation of error terms. It is called "cluster-specific fixed effects" and is a common approach to control for errors that might be related (Cameron & Miller, 2015, p. 329). Consider equation (10).

$$\epsilon = \epsilon_{\theta} + \epsilon_{\phi} + \epsilon_{\eta} + \epsilon_{\mu} + \epsilon_{\psi} + \epsilon_{imy} \tag{10}$$

Where ϵ is the hypothetical error term for equation (1), should we fail to include the proper fixed effects. Further, ϵ_θ, ϵ_ϕ, ϵ_η ,ϵ_μ , and ϵ_ψ are the potentially time-related medicinal, recreational, month and year error terms, respectively, while ϵ_η is the spatially related neighborhood errors, and ϵ_{imy} is the independent errors for home *i* selling in month *m* of year *y*. But then, by employing fixed effects in equation (1), equation (10) is reduced to equation (11).

$$\epsilon = \epsilon_{imy} \tag{11}$$

Thus, by including the appropriate cluster-specific fixed effects, we have taken an error term that was likely not independently and identically distributed and transformed it into one that is (Cameron & Miller, 2015) (Gujarati, et al., 2009). Thus, our fixed effects of equations (1), (3), and (4) go a long way toward addressing the above concerns of serial and spatial autocorrelation.

However, if the relationship between the errors is powerful, “cluster-specific fixed effects may not fully control for the cluster correlation” (Cameron & Miller, 2015, p. 330). If this is the case, one must employ cluster robust errors and cluster-specific fixed effects (Cameron & Miller, 2015). But one must then determine which errors are most in need of clustering. This turns out to be a nuanced question. The first step of clustering one’s errors is the determination of the suitability of the clusters available. In our case, serial autocorrelation issues are likely the most concerning. This is because they potentially affect our interpretation of the significance of our primary variables of interest: marijuana revenue. Additionally, several of our initial data sets were time series in nature. Thus, serial autocorrelation is the most probable and threatening type of autocorrelation our data faces. Hence, let us consider the clustering of our errors on time.

Our first concern regards the unit of time to cluster on. The general guidelines are “to use bigger and more aggregate clusters when possible, up to and including the point at which there is a concern about having too few clusters” (Cameron & Miller, 2015, p. 333). But concerning what represents “too few clusters,” we are advised that “there is no simple hard and fast rule regarding how” many clusters constitutes “too few” and thus “more is better” (Cameron & Miller, 2015, pp. 333,341,367). However, for a balanced dataset such as ours, we are told that between 20 to 50 clusters are acceptable (Cameron & Miller, 2015). In fact, one should “Beware of studies with a small number of clusters” (Ozler, 2012). When one possesses fewer than 20 clusters or too few observations per cluster, over-inflated p-values result. Thus, using “too few clusters" leads to an over-acceptance bias of the null hypothesis.

That is, if one has a small number of clusters or many clusters with few observations per cluster, you are prone to falsely reject the alternative hypothesis (Cameron & Miller, 2015).

Given the above, we need to cluster on the most aggregate level of time possible. Ordinarily, the year level is the most aggregate. However, we have only seven years of data. Thus, we are well below the minimum of 20 yearly clusters. Even if biannual clusters are employed, only 14 clusters result. Therefore, we settle on the use of quarterly time clusters. Given the constraints of our data, clustering our errors on the quarterly date is the Goldilocks solution. We have a sufficient number of clusters (25), allow errors to be related between nearby periods, and account for any remaining serial autocorrelation. Note that we cannot use monthly clusters because our periodicity is monthly. Clustering allows errors to be related within clusters but not across them. Thus, clustering on the month of the home sale would be tantamount to assuming there was no serial autocorrelation and using standard errors. There is one final advantage to using cluster robust errors. It simultaneously addresses possible autocorrelations within clusters and the presence of heteroskedasticity in the data. These properties of "cluster-robust" errors led Cameron & Miller (2015) to conclude that such errors should be termed "heteroskedastic-and cluster-robust" (Cameron & Miller, 2015, p. 321). Given that our data possesses heteroskedasticity, this is a significant benefit.

What we have thus far proposed is one-way clustering on time. This is likely sufficient, given our use of the spatial cluster-specific fixed effects for neighborhoods. However, it is possible to undertake what is known as multiway clustering. This is done when one suspects both spatial and serial autocorrelation remain after using cluster-specific fixed effects (Cameron & Miller, 2015). However, multiway clustering brings with it a danger. As Cameron & Miller (2015) state, "the few-clusters problem is more likely to arise if there is multiway clustering." This is because it is not merely enough to have a sufficient number of clusters: there must also be an adequate number of observations per cluster (Cameron & Miller, 2015, p. 349). Thus, the more ways one clusters, the more potential for too few clusters or observations. We have reason to believe that multiway clustering on neighborhood and quarterly date would invite "the few-clusters problem" (Cameron & Miller, 2015, p. 349). Consider that our smallest quarterly date cluster boasts 631 observations. Now compare that to the smallest neighborhood cluster with only two observations. Three such clusters exist, and several others only have 3-10 observations. Thus, despite our impressive 259 neighborhood clusters, their use would likely introduce bias to our results.

There is one final consideration. Some researchers have erroneously attempted “to cluster at the intersection of the two groupings.” In our case, we would be guilty of such maleficence if we attempted to cluster on neighborhood year. But such an approach will “be very inadequate because it imposes the restriction that observations are independent if they are in the same” neighborhood “but in different years.” Yet this is “identical to using heteroskedastic-robust standard errors—that is, not clustering at all” (Cameron & Miller, 2015, p. 336).

For all the above reasons, we conclude that the soundest way forward is the employment of spatial and serial cluster-specific fixed effects in conjunction with one-way clustering on the quarterly date. We follow Cameron & Miller (2015) in this. They suggest that when one is faced with both potential spatial and serial autocorrelations that one “try to add sufficient control variables so as to minimize concerns about clustering in one of the ways, and then use a one-way few-clusters cluster robust approach on the other way” (Cameron & Miller, 2015, p. 350). This is perhaps why existing literature on our topic has also heeded the above advice. Burkhardt & Flyr (2019) included fixed effects for time to account for any serial correlation. Simultaneously, they employed one-way spatially clustered errors to deal with any potentially remaining spatial autocorrelation. Cheng, et al. (2018) do virtually the same thing via the inclusion of time-fixed effects, and one-way clustering on municipalities. Thus, our approach is in keeping with the bulk of the literature on this topic.

Finally, consider table 5. There we present our comparison of equation (1)’s results with standard errors (STD ERR), heteroskedasticity robust errors (Robust), heteroskedasticity few-clusters robust, cluster robust errors (HFCR), and multiway heteroskedasticity cluster robust errors (MHCR).

Almost all the p-values of our independent variables are unchanged when using different error types. However, Standard errors did change. There are two exceptions. First, when we use clustered errors, medicinal marijuana goes from significance at the 10% level to insignificance. Also, in the last specification with multiway clustering, stories become significant only at the 10% level. But most importantly, in all specifications, the significance of the association between the natural log of the sale price of a home and the natural log of the amount of recreational marijuana revenue remained at the 1% level. It is striking that the significance of our primary variable of interest remains so strong, even when the multiway clustering is over biasing rejection of the alternative hypothesis. Note that choice of error type does not affect the coefficient estimation. It affects t-statistics, standard error estimation, and p-values (Cameron & Miller, 2015). This is all in keeping with our observations in table 5.

Table 5: One-Way and Multiway Clustering

$\ln(y_{imy})$ Variables	Hedonic: Eqn(1): STD ERR	Hedonic: Eqn(1): Robust	Hedonic: Eqn(1): HFCR	Hedonic: Eqn(1): MHCR
Intercept	3.3388*** (0.1845)	3.3388*** (0.1886)	3.3388*** (0.3221)	3.3388*** (0.4662)
ln(Living Area)	0.3079*** (0.0036)	0.3079*** (0.0039)	0.3079*** (0.0063)	0.3079*** (0.0192)
ln(Lot size)	0.1293*** (0.0031)	0.1293*** (0.0035)	0.1293*** (0.0038)	0.1293*** (0.0162)
Garage Area	0.0001*** (0.00001)	0.0001*** (0.00001)	0.0001*** (0.00001)	0.0001*** (0.00001)
No. Full Baths	0.1049*** (0.0012)	0.1049*** (0.0015)	0.1049*** (0.0014)	0.1049*** (0.0046)
No. Half Baths	0.0574*** (0.0019)	0.0574*** (0.0021)	0.0574*** (0.0027)	0.0574*** (0.0074)
No. Fireplaces	0.0306*** (0.0012)	0.0306*** (0.0013)	0.0306*** (0.0013)	0.0306*** (0.0028)
Stories	-0.0215*** (0.0027)	-0.0215*** (0.0029)	-0.0215*** (0.0035)	-0.0215* (0.0118)
Year Effectively Built	0.0021*** (0.00001)	0.0021*** (0.0001)	0.0021*** (0.0001)	0.0021*** (0.0002)
ln(MedRev)	-0.0107* (0.0062)	-0.017* (0.0064)	-0.0107 (0.0116)	-0.0107 (0.0129)
ln(RecRev)	0.0741*** (0.0091)	0.0741*** (0.0093)	0.0741*** (0.0204)	0.0741*** (0.0196)
Material FE(13)	Yes	Yes	Yes	Yes
Neighborhood FE(258)	Yes	Yes	Yes	Yes
Month FE(11)	Yes	Yes	Yes	Yes
Year FE(6)	Yes	Yes	Yes	Yes
R^2	0.9299	0.9299	0.9299	0.9299
AIC	-46,342.93	-46,342.93	-46,892.93	-46,344.93
Observations	39,863	39,863	39,863	39,863

Finally, the AIC scores indicate the model with Cameron & Miller's (2015) heteroskedasticity few-clusters robust, cluster robust errors best fit the data. Thus, we are theoretically and empirically justified in selecting this approach to dealing with potential serial and spatial autocorrelations.

Appendix IV: Ideal Marijuana Lag Structure

There is reason to suspect the amount of marijuana revenue from a given month is associated with later home prices. The decision to purchase might be related to cash on hand several months before the home sale. This is owing to the time it takes to find, make an offer, and finally close on a home purchase. Further, it will take more time for the market prices to adjust to the home sale information (Waugh, 1964). Basically, we need to check the robustness of our results from table 2 via differing lags of marijuana revenue. Hence, we estimate equation (1) with six different lag structures.

Column 1 contains our unlagged results for equation (1). In the 2nd, 3rd, 4th, 5th, 6th, and 7th columns, we have estimates of equation (1) using; 1, 2, 3, 4, 5, and finally 6-month lags, respectively. As previously discussed, this was done to account for the possibility that previous periods of marijuana revenue might be impacting home sales differently. We see that the sign and statistical significance of our recreational marijuana revenue results remain unchanged. The only observable difference is that the inclusion of lags decreases the magnitude of the recreational marijuana coefficient. Also, such a model has an ever so slightly higher R-squared. The simultaneous inclusion of all lag structures was also undertaken but not presented. However, the R-squared remained almost identical to the best-fitting model with 6 lags. Thus, we gained no explanatory power with the simultaneous inclusion of all lags. But by having multiple lags, all representing the same data trend, there was high collinearity between the various marijuana period variables. Hence, to avoid collinearity, we include only the best-fitting lag. The AIC score indicates the 6th-period lag model as best fitting our data. In fact, as we lagged further back, the model fit improved up to the 6th lag. However, after the 6th lag, the model fit began to deteriorate. Additionally, the 6th lag model had the highest R-squared figure achieved. Finally, the use of such a lag period is logical. We know it can take time to purchase a home. You must have the funds, locate and make an offer, and finally close the sale (Zillow, 2021b) (Zillow, 2021c). Then more time is required for market prices to adjust (Waugh, 1964) (Rosen, 1974). For all the above reasons, using a six-period lag has proven ideal.

Table 6: Marijuana Lag Regression Comparisons

$\ln(y_{imy})$ Variables	Hedonic: Eqn(1): No lag	Hedonic: Eqn(1): 1 lag	Hedonic: Eqn(1): 2 lags	Hedonic: Eqn(1): 3 lags	Hedonic: Eqn(1): 4 lags	Hedonic: Eqn(1): 5 lags	Hedonic: Eqn(1): 6 lags
Intercept	3.3388*** (0.3221)	4.4394*** (0.2686)	4.2747*** (0.2655)	4.2618*** (0.2454)	4.4231*** (0.291)	4.2565*** (0.2308)	4.0433*** (0.2479)
ln(Living Area)	0.3079*** (0.0063)	0.3078*** (0.0063)	0.308*** (0.0063)	0.308*** (0.0063)	0.308*** (0.0063)	0.3081*** (0.0063)	0.3082*** (0.0063)
ln(Lot size)	0.1293*** (0.0038)	0.1292*** (0.0038)	0.1292*** (0.0038)	0.1292*** (0.0038)	0.1292*** (0.0038)	0.1292*** (0.0038)	0.1292*** (0.0038)
Garage Area	0.0001*** (0.00001)	0.0001*** (0.00001)	0.0001*** (0.00001)	0.0001*** (0.00001)	0.0001*** (0.00001)	0.0001*** (0.00001)	0.0001*** (0.00001)
No. Full Baths	0.105*** (0.0015)	0.105*** (0.0014)	0.105*** (0.0014)	0.105*** (0.0015)	0.105*** (0.0015)	0.1049*** (0.0015)	0.1049*** (0.0015)
No. Half Baths	0.0574*** (0.0028)	0.0574*** (0.0028)	0.0574*** (0.0028)	0.0575*** (0.0028)	0.0576*** (0.0028)	0.0576*** (0.0028)	0.0574*** (0.0028)
No. Fireplaces	0.0306*** (0.0013)	0.0306*** (0.0013)	0.0306*** (0.0013)	0.0306*** (0.0013)	0.0306*** (0.0013)	0.0306*** (0.0013)	0.0306*** (0.0013)
Stories	-0.022*** (0.0033)	-0.021*** (0.0035)	-0.021*** (0.0035)	-0.022*** (0.0034)	-0.022*** (0.0035)	-0.022*** (0.0035)	-0.021*** (0.0035)
Year Effectively Built	0.0021*** (0.0001)	0.0021*** (0.0001)	0.0021*** (0.0001)	0.0021*** (0.0001)	0.0021*** (0.0001)	0.0021*** (0.0001)	0.0021*** (0.0001)
ln(MedRev)	-0.0107 (0.0116)	-0.0063 (0.0128)	0.0036 (0.0112)	0.0046 (0.0114)	-0.0045 (0.0142)	0.0055 (0.0116)	0.0189 (0.1181)
ln(RecRev)	0.0741*** (0.0197)	0.0017** (0.0006)	0.002*** (0.0006)	0.0022*** (0.0006)	0.0022*** (0.0006)	0.0019*** (0.0006)	0.0022*** (0.0004)
Material FE(13)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Neighborhood FE(258)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE(11)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE(6)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.9299	0.9298	0.9298	0.9299	0.9299	0.9299	0.9300
AIC	-46,892.93	-46,840.97	-46,859.79	-46,891.49	-46,899.89	-46,900	-46,934.5
Observations	39,863	39,863	39,863	39,863	39,863	39,863	39,863

Appendix V: Monthly Net Migration Data

The Colorado State Demography Office was our source for records on net migration rates for Denver County (Colorado Department of Local Affairs, 2022). The Demography Office was selected because it is "The most accurate source for such data" (Erffmeyer, 2021). The records concern January 1st, 2014, through February 29th, 2020. However, such data only exists with an annual periodicity. Yet, all other records used in our analysis are of a monthly periodicity. Thus, we employed a "common way to" deal with such a situation, called "cubic spline interpolation" (Columbia Economics L.L.C., 2010) (Montgomery, et al., 2001, pp. 228-230). Cubic spline interpolation uses a cubic spline function to estimate values that best fit a smooth cubic curve between observed data points. Via this method, we calculated monthly values of net migration for Denver County. However, this technique ensures that the data created will suffer from autocorrelation. This occurs because the spline function relates each estimate to the previous and subsequent estimates (Columbia Economics L.L.C., 2010). However, we overcome this serial autocorrelation by employing cluster-specific fixed effects and cluster robust standard errors (Cameron & Miller, 2015). This is taken up in more detail in appendix iii: cluster robust errors.

Appendix VI: Age at Sale vs. Effective Year Built

Table 7: Age at Sale vs. Year Effectively Built

$\ln(y_{imy})$ Variables	Hedonic: Eqn(1): Year	Hedonic: Eqn(1): Age
Intercept	4.0434*** (0.2479)	8.3033*** (0.2141)
ln(Living Area)	0.3082*** (0.0063)	0.3205*** (0.0060)
ln(Lot size)	0.1292*** (0.038)	0.1198*** (0.0038)
Garage Area	0.0001*** (0.00001)	0.0001*** (0.00001)
Fireplaces	0.0306*** (0.0013)	0.0297*** (0.0013)
Full Baths	0.1049*** (0.0015)	0.1101*** (0.0015)
Half Baths	0.0574*** (0.0028)	0.0607*** (0.0029)
Stories	-0.0214*** (0.0035)	-0.0198*** (0.0033)
Age At Sale	No	-0.0014*** (0.0001)
Year Effectively Built	0.0021*** (0.0001)	No
ln(MedRev6)	0.0189 (0.0118)	0.0184 (0.0122)
ln(RecRev6)	0.0022*** (0.0004)	0.0024*** (0.0131)
Material FE(13)	Yes	Yes
Neighborhood FE(258)	Yes	Yes
Month FE(11)	Yes	Yes
Year FE(6)	Yes	Yes
R^2	0.9300	0.9279
AIC	-46,934.50	-45,781.99
Observations	39,863	39,863

One of the essential advantages of hedonic models is their ability to include age-related depreciation and renovations (Case, et al., 1991). Additionally, age-related information controls for the changes in consumer home style preferences (Shiller & Case, 1987). We can account for depreciation, renovations, and changes in consumer tastes with the effective year of home construction (Erffmeyer, 2021). However, to be sure of the appropriateness of our choice, consider the results in table 7. There we employ the effective year of home construction and then substitute the age of the property at the time of sale in our estimation of equation (1).

Table 7 shows that our model estimates signs, significance, and magnitudes are almost identical between specifications. One exception is the effective year of construction vs. age at time of sale. The effective year is positive and statistically significant. It tells us that if a home is effectively one year younger, its value increases. Conversely, age at time of sale is negative and statistically significant. This implies that as the house gets older, its value decreases. As inverses of each other, both are consistent with the impact of age on home values (Sirmans, et al., 2006) (Price, et al., 2010) (Neill, et al., 2007). Concerning best fit, using the year of effective construction has a slightly higher R-squared. Yet most importantly, the AIC score indicates this specification to be a substantially better fitting one. Thus, we can see that employing the year of effective construction results in a superior model.

Appendix VII: Cluster Robust Errors

Consider that we employ the data of Rasmussen (2021). But such records were almost certainly affected by spatial and serial autocorrelations. This is because the data contains records on time series variables, such as marijuana revenue, average wages, net migration, and the number of people employed. But we know that "a key feature of time series data is that observations falling close to each other in time are not independent but rather tend to be correlated with each other" (Stock & Watson, 2007, p. 129). Thus, Rasmussen (2021) followed the recommendations of Cameron & Miller (2015) to employ a combination of "cluster-specific fixed effects" in conjunction with heteroskedasticity few-cluster robust, cluster robust errors (Cameron & Miller, 2015, p. 356).

Considering equations (4), (5), and (9) of the main chapter, one witnesses that we have already followed Rasmussen (2021) and Cameron & Miller (2015) via the inclusion of cluster-specific fixed effects. However, it remains to be seen if the use of clustering is as beneficial as it was for Rasmussen (2021). Thus, consider our comparison of equation (4)'s results with standard errors (STD ERR), heteroskedasticity robust errors (Robust), heteroskedasticity few-clusters robust, cluster robust errors (HFCR), and multiway heteroskedasticity cluster robust errors (MHCR). The results of such work are in table 8.

Table 8: One-Way and Multiway Clustering

$\ln\left(\frac{P_i}{1-P_i}\right)$ Variables	Logit: Eqn(4): STD ERR	Logit: Eqn(4): Robust	Logit: Eqn(4): HFCR	Logit: Eqn(4): MHCR
Intercept	-25.5556*** (4.7432)	-25.5551*** (4.5737)	-25.5551*** (9.3521)	-25.5551*** (9.4006)
ln(Living Area)	-0.2362*** (0.0790)	-0.2362*** (0.0779)	-0.2362** (0.0917)	-0.2362 (0.1532)
ln(Lot size)	-0.4279*** (0.0686)	-0.4279*** (0.0678)	-0.4279*** (0.0839)	-0.4279*** (0.1244)
Garage Area	0.00001 (0.0001)	0.00001 (0.0001)	0.00001 (0.0001)	0.00001 (0.0001)
No. Full Baths	0.1480*** (0.0268)	0.1480*** (0.0270)	0.1480*** (0.0309)	0.1480*** (0.0386)
No. Half Baths	0.0357 (0.0412)	0.0357 (0.0412)	0.0357 (0.0027)	0.0357 (0.0499)
No. Fireplaces	-0.0135 (0.0250)	-0.0135 (0.0247)	-0.0135 (0.0013)	-0.0135 (0.0358)
Stories	0.0205 (0.0586)	0.0205 (0.0247)	0.0205 (0.0715)	0.0205 (0.1424)
Year Effectively Built	0.0020** (0.0009)	0.0020** (0.0009)	0.0020*** (0.0007)	0.0020* (0.0012)
ln(MedRev)	-0.1753 (0.2048)	-0.1753 (0.2079)	-0.1753 (0.4221)	-0.1753 (0.4330)
ln(RecRev)	1.4988*** (0.2600)	1.4988*** (0.2467)	1.4988*** (0.5424)	1.4988*** (0.5559)
Material FE(13)	Yes	Yes	Yes	Yes
Neighborhood FE(258)	Yes	Yes	Yes	Yes
Month FE(11)	Yes	Yes	Yes	Yes
Year FE(6)	Yes	Yes	Yes	Yes
AIC	29,680.87	29,680.87	29,150.87	29,680.87
Observations	39,778	39,778	39,778	39,778

Our logit model best fits the data when we conduct one-way clustering on the quarterly date. This is evidenced by the AIC scores of the different model specifications (Baguley, 2012). Additionally, when we attempt multiway clustering on the quarterly date and the neighborhood, we find strong evidence that our resulting standard errors and p-values suffer from “too few clusters, or observations” (Rasmussen, 2021, p. 74). The problem with multiway clustering is that several of the 249 neighborhood clusters possess only 2 to 10 observations per cluster.

For all these reasons, we implement Cameron & Miller's (2015) heteroskedasticity few clusters robust, cluster robust errors. For a more detailed discussion of this topic, see appendix iii: cluster robust errors. Note that the approach of Cameron & Miller (2015) approach is at home in logit and probit regression analysis (Cameron & Miller, 2015).

Appendix VIII: Ideal Lag Structure

Table 9: Marijuana Lag Regression Comparisons

$\ln\left(\frac{P_i}{1-P_i}\right)$ Variables	Logit: Eqn(4): No lag	Logit: Eqn(4): 1 lag	Logit: Eqn(4): 2 lags	Logit: Eqn(4): 3 lags	Logit: Eqn(4): 4 lags	Logit: Eqn(4): 5 lags	Logit: Eqn(4): 6 lags
Intercept	-25.56*** (9.35)	-20.17*** (7.12)	-10.4037 (7.8466)	-11.9499 (9.2325)	-6.1656 (6.7249)	-2.7572 (5.8862)	-3.0836 (5.6477)
ln(Living Area)	-0.2362** (0.0917)	-0.2361** (0.0919)	-0.2348** (0.0915)	-0.2345** (0.0914)	-0.2347** (0.0916)	-0.2333** (0.0917)	-0.2341** (0.0913)
ln(Lot size)	-0.428*** (0.0839)	-0.428*** (0.0848)	-0.428*** (0.0849)	-0.427*** (0.0842)	-0.428*** (0.0844)	-0.429*** (0.0843)	-0.428*** (0.0848)
Garage Area	0.00001 (0.0001)	0.00001 (0.0001)	0.00001 (0.0001)	0.00001 (0.0001)	0.00001 (0.0001)	0.00001 (0.0001)	0.00001 (0.0001)
No. Full Baths	0.1480*** (0.0309)	0.1478*** (0.0311)	0.1477*** (0.0312)	0.1478*** (0.0309)	0.1478*** (0.0309)	0.1478*** (0.0309)	0.1481*** (0.0309)
No. Half Baths	0.0357 (0.0404)	0.0360 (0.0404)	0.0366 (0.0311)	0.0362 (0.0406)	0.0367 (0.0405)	0.0369 (0.0404)	0.0367*** (0.0405)
No. Fireplaces	-0.0135 (0.0252)	-0.0125 (0.0251)	-0.0135 (0.0250)	-0.0139 (0.0251)	-0.0136 (0.0250)	-0.0134 (0.0251)	-0.0130 (0.0250)
Stories	0.0205 (0.0715)	0.0201 (0.0716)	0.0193 (0.0714)	0.0194 (0.0715)	0.0197 (0.0716)	0.0195 (0.0717)	0.0195 (0.0713)
Year Effectively Built	0.0020*** (0.0007)	0.0020*** (0.0007)	0.0020*** (0.0007)	0.0020*** (0.0007)	0.0020*** (0.0007)	0.0020*** (0.0007)	0.0020*** (0.0007)
ln(MedRev)	-0.1753 (0.4221)	0.1060 (0.0128)	0.0528 (0.3539)	-0.1697 (0.3557)	-0.0965 (0.3973)	-0.3336 (0.3111)	-0.3489 (0.3115)
ln(RecRev)	1.4988*** (0.5425)	0.8827 (0.5397)	0.3362 (0.4521)	0.6651 (0.5594)	0.2414*** (0.0733)	0.2872*** (0.3111)	0.3337*** (0.0776)
Material FE(13)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Neighborhood FE(258)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE(11)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE(6)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
AIC	29,150.87	29,166.84	29,175.95	29,161.64	29,158.37	29,140.26	29,119.61
Observations	39,778	39,778	39,778	39,778	39,778	39,778	39,778

Above, we compare lag model structures. In so doing, we observe that the signs, significances, and even the magnitude of our housing characteristic estimates remain almost identical from model to model. Notably, this does not include our primary variable of interest, recreational marijuana. While it maintains a positive coefficient of roughly equal magnitude, the significance of recreational marijuana changes with the lag period selected. Specifically, recreational marijuana lags 1-3 are insignificant. However, lags 1-3 also have the worst AIC score of all lags presented. In fact, we observe that as the model's fit improves, the coefficient on recreational marijuana becomes significant at the 1% level once again. The AIC scores indicate that the best-fitting model possesses a six-month lag between the amount of marijuana revenue generated and the log odds ratio of a home reselling. This matches the findings of Rasmussen (2021). There it was similarly determined that the best-fitting model possessed a six-month lag between the amount of recreational marijuana generated and home prices. Finally, do not simultaneously include all our lags in the same model. This is done to avoid multicollinearity. However, we conducted lag analysis out to twelve periods, and each period after six months was ever worse in terms of fitting the data.

Appendix IX: Percent Change in Probability of Denver Home Resale

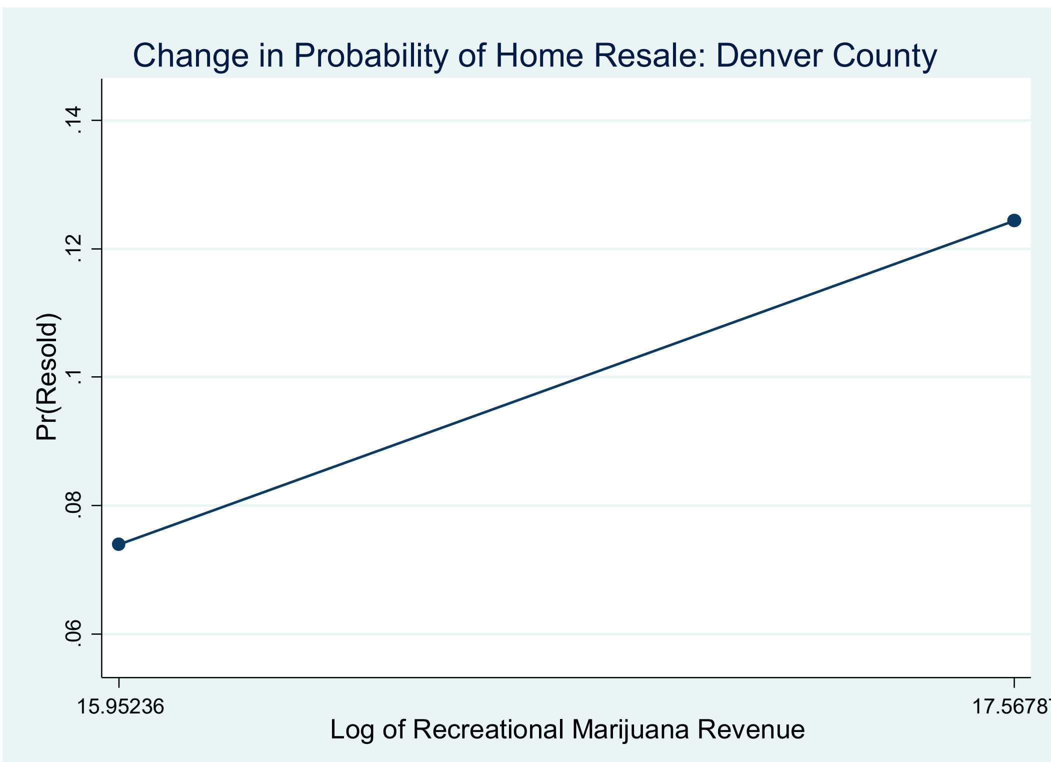

Figure 24. Percent Change in Probability of Denver Home Resale

Here we calculate the exact change in the probability of a home reselling in Denver County. This is done from peak to trough of legal recreational marijuana revenue generated. All other variables are held at their mean values. We find the probability of a home reselling when recreational marijuana revenue is at its trough to be 7.39464%. Conversely, when recreational marijuana peaks, the likelihood of a home reselling is 12.432%. So, there is an approximate 68.12% increase in the probability that a home will resell over our sample values of recreational marijuana revenue. Put another way, the likelihood that a home will resell has increased by roughly 5.05 percentage points. Furthermore, the above increases are shown in table 4 to be associated with the amount of recreational marijuana revenue generated in Denver County.

Appendix X: Exclusion of Neighborhood and Month Controls

This comparison was undertaken to establish the suitability of including neighborhood and month controls in our estimates of equations (4), (5), and (9). Almost all the signs and significances remain similar between the housing characteristics of the models. However, the year of effective construction transitions from negative and insignificant to positive and significant once neighborhood controls are included. Without neighborhood-fixed effects, medicinal and recreational marijuana results remain virtually unchanged. However, when we exclude monthly fixed effects, there are notable changes to our variables of interest. Firstly, the six-month lag of recreational marijuana revenue shifts from significance at the 1% to the 10% level. More notably, medicinal marijuana has become significant at the 5% level. Such changes are likely why Shiller & Case (1987) and Reichert (1990) discuss the importance of accounting for possible seasonal demand for different types of homes. Specifically, homes more prone to resale enjoy increased demand in the later months of the year (Shiller & Case, 1987) (Clap & Giaccotto, 1992) (Reichert, 1990). Thus, our analysis further highlights the importance of accounting for seasonal demand in regional home resale models. Most importantly, note that the AIC measure indicates the specification possessing both month and neighborhood fixed effects as best fitting the data (Baguley, 2012). Thus, we follow Rasmussen (2021) and retain both month and neighborhood fixed effects. Pace & Zhu (2019) similarly determined neighborhood controls to be associated with home sale probability. Also, we know that including neighborhood and month-fixed effects is vital to account for any potential spatial and serial autocorrelation in our data (Cameron & Miller, 2015). Note that the first specification without neighborhood effects had 39,863 observations compared with 39,778 with neighborhood fixed effects. This change occurred because there were 85 home sales in neighborhoods where no resales took place. Thus, those neighborhoods perfectly predicted failure to resell and were omitted.

Therefore, another benefit of this analysis is the observation that removing those 10 neighborhoods from our primary analysis does not affect our findings.

Table 10: Control Exclusions

$\ln\left(\frac{P_i}{1-P_i}\right)$ Variables	Logit: Eqn(4): Month, No NBHD	Logit: Eqn(4): No Month, NBHD	Logit: Eqn(4): NBHD, Month
Intercept	0.1863 (5.4095)	-3.4359 (8.4269)	-3.0836 (5.6477)
ln(Living Area)	-0.3382*** (0.0900)	-0.2408*** (0.0911)	-0.2341** (0.0913)
ln(Lot size)	-0.3336*** (0.0406)	-0.4278*** (0.0841)	-0.4282*** (0.0848)
Garage Area	-0.00002 (0.0001)	0.00001 (0.0001)	0.00001 (0.0001)
No. Full Baths	0.1472*** (0.0289)	0.1494*** (0.0366)	0.1481*** (0.0310)
No. Half Baths	0.0113 (0.0405)	0.0365 (0.0413)	0.0367 (0.0405)
No. Fireplaces	0.0233 (0.0239)	-0.0113 (0.0247)	-0.0130 (0.0250)
Stories	0.0103 (0.0737)	0.0181 (0.0716)	0.0195 (0.0713)
Year Effectively Built	-0.00003 (0.0006)	0.0020*** (0.0007)	0.0020*** (0.0007)
ln(MedRev6)	-0.2896 (0.3004)	-0.8269** (0.3236)	-0.3489 (0.3115)
ln(RecRev6)	0.3327*** (0.0757)	0.8746* (0.4536)	0.3337*** (0.0776)
Material FE(13)	Yes	Yes	Yes
Neighborhood FE(248)	No	Yes	Yes
Month FE(11)	Yes	No	Yes
Year FE(6)	Yes	Yes	Yes
AIC	29,668.67	29,170.68	29,119.61
Observations	39,863	39,778	39,778

Appendix XI: Creation of Resold Dependent Variable

Our research question regards a possible association between marijuana sales revenue and the chance that a Denver County home will resell. Thus, the creation of a binary dependent outcome variable was demanded. This dependent variable takes on a value of 1 if a home resold in our sample period and 0 if no resale occurred. The designation of our binary dependent variable is RESOLD. Several steps were involved in the creation of RESOLD. First, we needed to ascertain the total number of times a home sold in our sample. This was achieved by creating RESALE_COUNT, which tallied the number of times a given unique property id appeared (sold) in our data set. But RESALE_COUNT lists the total number of times a property was sold in the sample period. Now suppose home *i* sold *n* times between January 1st, 2014, and February 29th, 2020. Thus, RESALE_COUNT would have a value of *n* for each observation of home *i* in the data. However, one of the primary assumptions of the logit model is that there are no repeated observations of the same unit in the dataset (Stoltzfus, 2011). Thus, we create an additional variable titled TIMES_SOLD, which indexes each occurrence of the same property. Such is achieved with a value from 1 to *n*, where home *i* sold *n* times. Thus, the first-time home *i* is seen in the data TIMES_SOLD equals 1, the second time 2, etc., to the *nth* observation of home *i.* We proceeded to keep only the latest observation of all resold homes. This was achieved by retaining only those resold homes where RESALE_COUNT was greater than or equal to 2 and TIMES_SOLD equaled *n*, the last time a resold home was sold in the sample period.

Having ensured that only the last sale of all resold homes remained, we created the needed binary variable RESOLD, where:

$$RESOLD \begin{Bmatrix} RESOLD = 1, & if\ RESALE\ COUNT \geq 2 \\ RESOLD = 0, & if\ RESALE\ COUNT < 2 \end{Bmatrix}$$