For office use only	Team Control Number	For office use only
T1 _____	1926047	F1 _____
T2 _____		F2 _____
T3 _____	Problem Chosen	F3 _____
T4 _____	C	F4 _____

2019

MCM/ICM

Summary Sheet

(Your team's summary should be included as the first page of your electronic submission.)

Type a summary of your results on this page. Do not include the name of your school, advisor, or team members on this page.

We examined the trends of drug consumption per household among each county in the five states provided: Ohio, Pennsylvania, Kentucky, Virginia, and West Virginia. Upon a preliminary investigation of trends, we observed that Ohio exhibited anomalously exponential drug report numbers over recent years, and thereby reasoned that it is the state which has and will have the most serious drug abuse problems for the coming years. We then designed appropriate growth models to predict drug consumption per household in Ohio and used the data to estimate an upper bound for Ohio's drug consumption. We discussed the assumptions and reliability of our models, and proposed improvements for the model.

The second-half of our project consisted of using methods of linear regression to examine the existence and strength of correlations between drug consumption and various socioeconomic factors, mainly consisting of distinct household classes. Using a residuals plot, we discussed the reliability of our model. We hope that by determining the epicenters of the crisis and establishing state-specific socioeconomic correlations to drug use, we will inform future policymaking and direct valuable resources to those most in need.

Keywords

Dynamical Systems, Exponential Growth Models, Regression Models, Statistical Analysis, Data Analysis

The Opioid Crisis

Team #1926047

January 29, 2019

Contents

1 Introduction

The Opioid Crisis is an ongoing epidemic in the United States involving the misuse and overdose of opioid prescriptions. The crisis began in the late 1990s, when pharmaceutical companies downplayed the addictive properties of opioid pain relievers, and healthcare providers consequently prescribed them at greater rates [1]. The increased prescriptions resulted in widespread misuse of both prescription and non-prescription opioids, and those who misuse opioids may also transition to heroin [1]. According to Center of Disease Control and Prevention [2], there has been a great surge in the number of heroin and synthetic opioids deaths in 2010 and 2013, respectively. In 2016, more than 42,000 Americans died by opioid overdosing, and this number rises every year [1][3].

1.1 The Rising Opioids

The euphoric feeling induced by opioids makes them effective pain relievers, or *narcotic analgesics*. While opiates are safe when prescribed by doctors for short periods of time, they are also easily misused. Misuse of opioids may lead to addiction, and addicted patients then begin searching for cheaper or more accessible alternatives, such as heroin or fentanyl [1][3].

Heroin is an illegal and highly addictive drug processed from morphine [4]. Though the use of heroin remained low, it began increasing in 2007 as those who misused opioid prescriptions transitioned to a cheaper alternative. A number of studies suggests that heroin is "cheaper, more available, and provides a better high" compared to prescription opioids [4].

Synthetic opioids include tramadol and fentanyl, and are highly potent drugs designed to imitate natural opioid effects. Fentanyl, which is 50 to 100 times more potent than morphine, has been prescribed to patients with severe pain or those who are physically tolerant to other opioids [6]. Due to their high potency, there has been a steep increase in overdose deaths caused by synthetic opioids which mostly involve illicitly-manufactured fentanyl.

1.2 Current Implemented Measures

Currently the Opioid Crisis involves the collected efforts of many organizations, including the Center for Disease Control and Prevention (CDC), Department of Health and Human Services (HHS), and the National Institutes of Health (NIH). Solutions addressing the crisis include:

- improving access to treatment and recovery services
- non-addictive alternative to relieve pain
- reversal of opioid addiction

More specifically, The HEAL (Helping to End Addiction Long-termSM) Initiative launched by NIH is helping patients become more susceptible to risks of using opioids, supporting research to prevent and treat opioid misuse and addiction, and testing new pain therapies that could substitute opioids [7].

HHS is also working to support opioid prevention, treatment, and recovery services and raise awareness of the epidemic through media and publications. It is targeting to increase the availability of overdose-reversing drugs, the move supported by the President's 2019 Budget of $74 million [8].

1.3 Our Approach

This paper explores the counties that might have been the source of opioid resurgence in terms of heroin and synthetic opioids in each of the five states: Ohio, Pennsylvania, Virginia, West Virginia and Kentucky and examine its spreading effects on neighboring counties using the diffusion model. We also study the correlation between several socioeconomic factors and drug consumption using the regression model. Understanding the spread and characteristics of opioid cases is pertinent to studying the Opioid Crisis and evaluating current implemented measures. From the models, we hope to be able to forecast and address the crisis in an informed and effective manner.

2 Methods of Identifying Trends and Model Designing

We use Python library pandas to import data sets on opioid use of each county from 5 states: Ohio, Pennsylvania, Virginia, West Virginia and Kentucky from National Forensic Laboratory Information System (NFLIS) and households information from US Census Bureau.

Through analysis of NFLIS data, we generate data tables and graphs that show the trend of drug use per household across counties with the most drug use per household in 2010 within each state over the years. From these, we can predict the growth of drug use in each of the five states by comparing the exponential and logistic growth model to determine when and where the threshold levels of drug consumption will occur in the near future.

We can also predict which factors have the most correlation on opioid addiction tendency by regression modeling the relationship between some indicators in the US Census Bureau data and considering the correlation coefficient as well as residuals plot to decide the fitness of the model.

3 Growth Models

3.1 Trends of drug consumption

- Drug Consumption Per Household Among and Within Each State (Refer to Graphs and Diagrams, Figure 4 and Figure 5)
  - For Pennsylvania, West Virginia and Kentucky, the numbers of reports per household over the years have been only slightly fluctuating.
  - Virginia, in particular, has a sudden surge in number of reports in 2013, which is identified as the year of synthetic opiods explosion by CDC, meaning that Virginia is likely to be a source of synthetic opioids explosion.
  - Ohio is the only state out of the five whose number of drug reports per household has been increasing at an increasing rate.
- Growth of Heroin and Synthetic Opioids Consumption Across The Five States
  - Heroin consumption: Looking at the top 10 counties in heroin consumption per household (by 2010 data), we can see that Richmond, VA has the most distinctive trend of drug consumption, hitting its peak in 2013, while the number of heroin report only fluctuates slightly. From this, we predict Richmond, VA to be the source of the local opioid crisis in Virginia. The trend of heroin

abuse in 2010 hit the hardest at Delaware, OH, but then decreased sharply and remained low in the later years, meaning that the drug crisis may have diffused to other counties.

– Fentanyl consumption: Looking at the top 10 counties of fentanyl consumption per household (by 2010 data) each of the five states except for West Virginia and Virginia has been increasing at an exponential rate since 2013. Virginia's fentanyl consumption in 2013 and 2016 increases sharply and decreases or remains low in 2010, 2012, 2015.

Therefore, we can consider the exponential and logistic growth model to predict overall drug consumption in Ohio and threshold level of drug consumption, as well as predicting the growth of heroin and fentanyl drug consumption across all five states.

3.2 Exponential Growth Model

The exponential model we propose to fit the data is as followed:

$$y = C + a^t$$

in which C is a constant, y is the total Ohio drug consumption (in terms of number of drug reports per household), t is the number of years from 2010 (in years), with 2010 is set to be year zero, a is a constant that is powered by t. At t = 0, y = 10.7, C = 10.7-1 = 9.7. Using, we adjust the value of C around 9, and adjust the value of accordingly such that the final equation fits the Ohio data. Thus, we are able to derive the following equation and plot the graph of total drug consumption per household in Ohio against time with logistic model.

$$y = 9.3 + 1.58^x$$

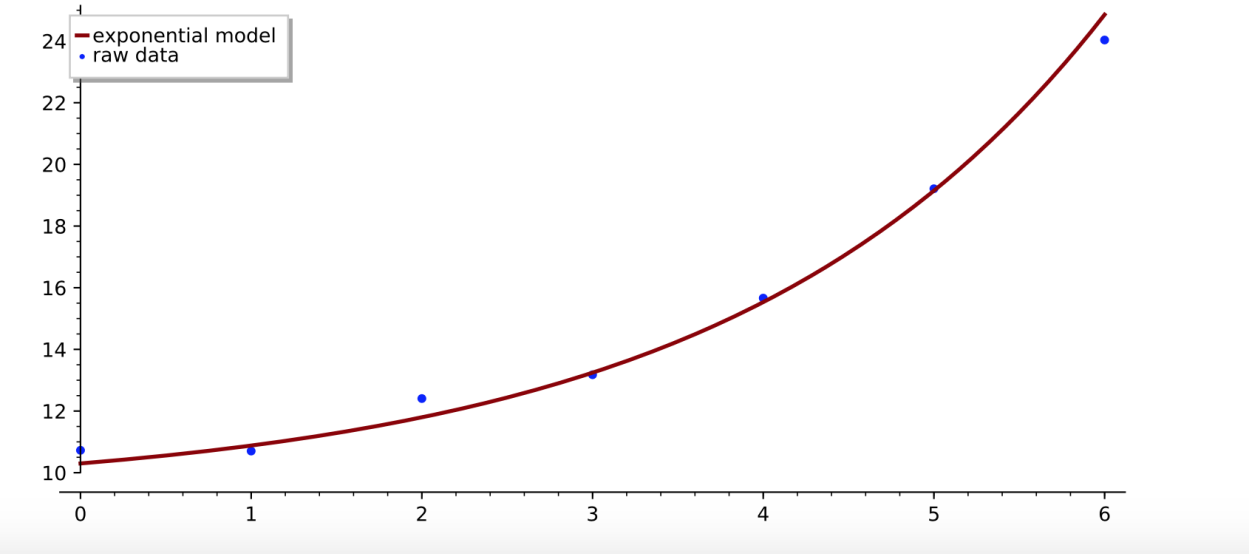

Figure 1: Exponential Growth Model for relationship between total drug consumption per household in Ohio and number of years from year 2010

3.3 Logistic Growth Model

The logistic model we propose to fit the data is as followed:

$$y = \frac{L}{(1 + e^{-k(t-t_0)} + C)}$$

in which C is a constant, L is the predicted maximum number of drug reports per household possible over time, t_0 is the value of t when y = half of L. k is the intrinsic growth rate of drug consumption per household for Ohio. Looking at the scatterplot, from 2010 to 2016 number of drug of drug reports in Ohio has been rising exponentially, so the fastest time that drug consumption would reach a threshold is $2t$, meaning that t = 6 is already midpoint.

Assuming that we want the number of drugs reports per household at around t = 6 to be half of the maximum number of drug reports per household possible, we adjust the value of t_0 between 5 and 7, adjust L around 10.7 + double of (24-10.7) and choose 40. Then we adjust other values of k = -0.67 and C = 2010's drug reports = 10.726 accordingly to fit the data. Thus, we are able to derive the following equation and plot the graph of total drug consumption per household in Ohio against time with logistic model.

$$y = \frac{40}{(1 + e^{-0.67(t-7)} + 10.726)}$$

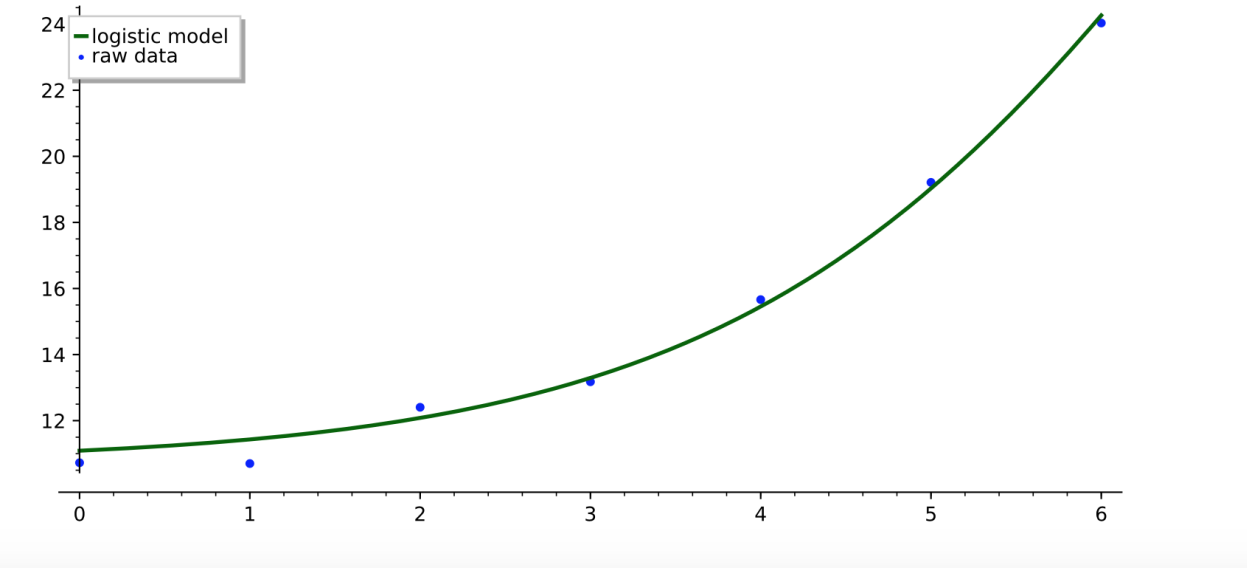

Figure 2: Logistic Growth Model for relationship between total drug consumption per household in Ohio and number of years from year 2010

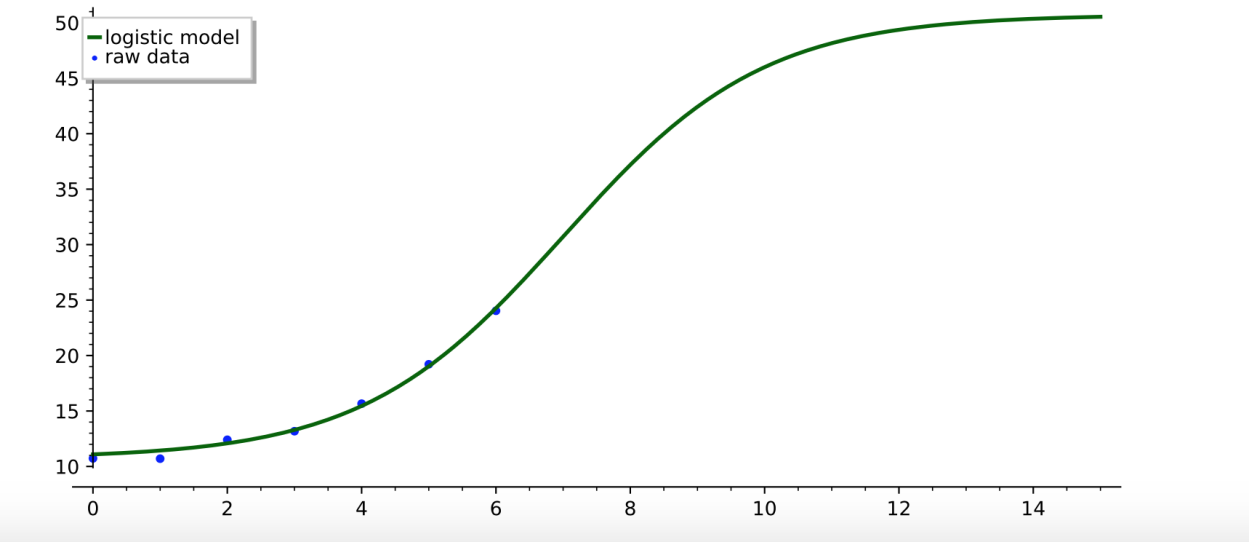

Figure 3: Logistic Model with threshold drug consumption per household in Ohio

3.4 Evaluation

There are certain limitations to both models. Exponential model may not be realistic because there are certain measures taken by the drug control agencies that can partly prevent the spread of drug abuse, so there should be a threshold level of drug consumption, which is taken account of in the logistic model. However, even in the logistic model, we have to look at the most positive case, which is assuming 2016-2017 to be the years in which drug consumption begins to increase at a decreasing rate and will reach a threshold level of around 50 drug reports, as shown above. We also have insufficient data as only data from 2010 to 2016 were considered, and a lot may change in the future regarding the use of heroin and synthetic opioids. There is a possibility of new synthetic opioids being created and worsening the drug crisis, and thus nothing may stop the drug consumption per household in Ohio from increasing at an alarming rate in the following years. We expect that the exponential model is more fitting at least in the near future.

4 Regression Model

4.1 Hypotheses on relationship between certain types of households and drug consumption

According to NIDA, socioeconomic conditions have one of the most significant impacts on the possibility of drug addiction. This is because:

- People living in more rural, unfavorable conditions are more susceptible to contracting diseases such as hepatitis due to poor hygienic conditions. Thus they are more likely to be in constant need of pain reliefs.

- A lot of them also have difficult access to high quality healthcare and thus have little knowledge about available resources or methods to relieve pain. Due to a stricter regulation on pain relief prescriptions, people with no access to quality healthcare services would find alternatives to legal narcotic analgesics, which include heroin and synthetic opioids (e.g. fentanyl).

Therefore, our assumptions are based on identifying groups that are more likely to live in unfavorable financial conditions and have low levels of education. These groups are:

- Single-person households with a child in rural neighborhoods, in which a single parent has to work alone to support the child with low accessibility to healthcare. The parent would have a limited time supervising the child, which could lead to the child's exposure to opioids.
- Males may be more vulnerable to drug abuse than females.
- People with lower education levels may not be aware of the addictive effect of pain relievers and may take them without doctor's prescription.
- People who do not speak English might not be able to obtain information on pain relievers.

4.2 Application in Identifying Indicators of Potential Drug Abuse

We are able to generate scatterplots of relationships between number of heroin reports per household of each state and total number of different types of households. Using stats.linregress function in Python, we are able to find the correlation coefficient for linear regression model of each relationship.

We include scatterplots with linear regression line, and residuals plot for the case of all types of households in section Graphs and Diagrams for the ease of visualization.

- General trend of drug consumption across all types of households:

Table 1A. Correlation Coefficients of Linear Regression Model of relationship between total heroin reports per household and total number of households in each state.

State	2010	2011	2012	2013	2014	2015	2016
Ohio	0.5795	0.6551	0.7524	0.7901	0.8319	0.8311	0.8181
Pennsylvania	0.8673	0.8835	0.8918	0.8809	0.8903	0.8806	0.8651
Kentucky	0.6665	0.7134	0.8787	0.8977	0.9145	0.9307	0.9245
Virginia	0.3420	0.7838	0.8287	0.4545	0.6522	0.6729	0.6964
West Virginia	0.2609	0.3783	0.3101	0.2940	0.3970	0.3460	0.3294

Table 1B. Correlation Coefficients of Linear Regression Model of relationship between total fentanyl reports per household and total number of households in each state.

State	2010	2011	2012	2013	2014	2015	2016
Ohio	0.4244	0.2737	0.1756	0.3985	0.5918	0.5667	0.7277
Pennsylvania	0.5465	0.5905	0.5795	0.5965	0.6736	0.8316	0.8470
Kentucky	0.3661	0.5039	0.2266	0.4468	0.4806	0.5111	0.8939
Virginia	0.2416	0.3264	0.1771	0.7129	0.6904	0.5875	0.7840
West Virginia	-0.0553	0.0005	0.0438	0.2757	0.2657	0.3173	0.4129

Looking at all types of households, there is a consistently strong correlation between total heroin reports per household and total number of households in Pennsylavnia, while the opposite applies for Virginia. There is an overall increase in correlation strength in the remaining states from 2010 to 2016. On the other hand, there seems to be weaker correlation between total fentanyl reports per household and total number of households than that with heroin reports, even with 2016 indicating the strongest correlation of the

relationship in all the states. In addition, the table on heroin consumption has higher correlation coefficient values for all states than that on fentanyl consumption. Let's delve into specific types of households and compare the correlation coefficients for relationships between total drug consumption per household and different types of households.

- Heroin consumption per household and types of household

Table 2.1A. Correlation Coefficients of Linear Regression Model of relationship between total heroin reports per household and total number of household of single female with a child < 18 years in each state.

State	2010	2011	2012	2013	2014	2015	2016
Ohio	0.5753	0.6519	0.7656	0.7933	0.8380	0.8362	0.8278
Pennsylvania	0.9447	0.9539	0.9493	0.9404	0.9209	0.9436	0.9355
Kentucky	0.6516	0.7065	0.8779	0.8975	0.9130	0.9309	0.9235
Virginia	0.3237	0.7440	0.7951	0.4189	0.6129	0.6365	0.6617
West Virginia	0.1538	0.2962	0.2466	0.3212	0.4535	0.3824	0.3717

Table 2.2A. Correlation Coefficients of Linear Regression Model of relationship between total heroin reports per household and total number of household of single male with a child < 18 years in each state.

State	2010	2011	2012	2013	2014	2015	2016
Ohio	0.6000	0.6947	0.7689	0.8057	0.8437	0.8454	0.8321
Pennsylvania	0.8874	0.9004	0.8963	0.9254	0.8824	0.9481	0.9487
Kentucky	0.6452	0.6988	0.8739	0.8928	0.9182	0.9297	0.9251
Virginia	0.3492	0.7790	0.8407	0.4484	0.6638	0.6891	0.7048
West Virginia	0.2790	0.3924	0.3798	0.2491	0.3432	0.2991	0.2815

Single male or female with a child below 18 years: Correlation coefficients over the years are consistently low ($0.15 < 0.46$) in WV and consistently high ($0.88 < 0.96$) in PA. This implies that there is a consistently strong correlation between number of heroin reports per household and number of single person households with a child in all counties of PA, while the trend of single person households with a child abusing heroin seems to have spread to all counties in OH, VA and KY over the years. The constant increase in correlation coefficients for these states supports our implication.
Meanwhile, there is not a noticeable difference between correlation coefficient for single male parent and single female parent households, so our hypothesis of males being more vulnerable to drug addiction may not be true.

Table 3.1A Correlation Coefficients of Linear Regression Model of relationship between total heroin reports per household and total number of household of people with education level 9th to 12th grade, no diploma.

State	2010	2011	2012	2013	2014	2015	2016
Ohio	0.5526	0.6312	0.7669	0.7711	0.8068	0.7928	0.7734
Pennsylvania	0.9241	0.9332	0.9156	0.8181	0.7398	0.8529	0.8670
Kentucky	0.6494	0.7115	0.8666	0.7798	0.7989	0.8274	0.8196
Virginia	0.2988	0.6965	0.7557	0.4029	0.5819	0.5931	0.6098
West Virginia	0.3255	0.5369	0.4778	0.3896	0.5417	0.4316	0.3706

Table 3.2A. Correlation Coefficients of Linear Regression Model of relationship between total heroin reports per household and total number of household of people with college education, no degree.

State	2010	2011	2012	2013	2014	2015	2016
Ohio	0.5781	0.6544	0.7508	0.7592	0.8051	0.8059	0.7924
Pennsylvania	0.8556	0.8782	0.8868	0.8827	0.8889	0.8905	0.8784
Kentucky	0.6668	0.7185	0.8848	0.8809	0.9092	0.9160	0.9099
Virginia	0.3487	0.7841	0.8257	0.4853	0.7147	0.7336	0.7526
West Virginia	0.1695	0.2705	0.2262	0.4393	0.5568	0.5182	0.4622

The correlation coefficient is consistently high for Pennsylvania in terms of relationship between heroin consumption per household and people with no high school diploma or college degree, and the opposite applies for West Virginia while increasing for Ohio, Kentucky and Virginia.
Comparing Virginia and Kentucky, we can see a weaker correlation in the relationship between total heroin consumption per household and total households of people with no high school diploma than that with those who have graduated from high school. Thus, our hypothesis that people with lower education may be more vulnerable to drug addiction may not be true, since there is a more consistent trend of consumption across all counties among people who have graduated high school.
The correlation coefficient trend of the number of drug reports per household for all states against total households of people who do not speak English very well is also similar to that of the indicators above.

Table 4A. Correlation Coefficients of Linear Regression Model of relationship between total heroin reports per household and total number of household of people who speak English less than "very well".

The constantly high correlation coefficient for Pennsylvania across all indicators suggests that there is a trend of increasing drug abuse in all groups of people across all counties, meaning the current measures to control the drug use in Pennsylvania have not been able to reach these groups at all.

State	2010	2011	2012	2013	2014	2015	2016
Ohio	0.4061	0.5066	0.6255	0.7834	0.8246	0.8228	0.8084
Pennsylvania	0.8562	0.8634	0.8323	0.8631	0.8725	0.8702	0.8560
Kentucky	0.5706	0.6045	0.7986	0.8985	0.9139	0.9308	0.9243
Virginia	0.2834	0.6817	0.7349	0.4525	0.6460	0.6665	0.6903
West Virginia	0.0446	0.0363	0.0299	0.2651	0.3549	0.3087	0.2980

- Fentanyl consumption per household and types of household

  For all indicators below, the correlation coefficient for relationship of total fentanyl reports per household and total households of different structures are lower than that for heroin reports, but it increases over the years for all states, which means the problem of fentanyl addiction has spread evenly to all counties in different categories of households.

Table 2.1B. Correlation Coefficients of Linear Regression Model of relationship between total fentanyl reports per household and total number of household of single female with a child < 18 years in each state.

State	2010	2011	2012	2013	2014	2015	2016
Ohio	0.4211	0.2552	0.1436	0.3834	0.5852	0.5652	0.7363
Pennsylvania	0.5831	0.6692	0.6468	0.5937	0.6244	0.8652	0.9055
Kentucky	0.3581	0.5196	0.2267	0.4338	0.4758	0.4995	0.8923
Virginia	0.1915	0.2719	0.1636	0.6632	0.6595	0.5323	0.7267
West Virginia	0.1538	0.2962	0.2466	0.3212	0.4535	0.3824	0.3717

Table 2.2B. Correlation Coefficients of Linear Regression Model of relationship between total fentanyl reports per household and total number of household of single male with a child < 18 years in each state.

State	2010	2011	2012	2013	2014	2015	2016
Ohio	0.4234	0.2688	0.1694	0.3986	0.5985	0.5768	0.7464
Pennsylvania	0.5694	0.6330	0.5933	0.6333	0.5616	0.7814	0.8546
Kentucky	0.3449	0.5147	0.2214	0.4306	0.4457	0.4766	0.8852
Virginia	0.2469	0.3170	0.1970	0.6500	0.6891	0.5877	0.7675
West Virginia	-0.0937	0.0596	0.0622	0.2434	0.2237	0.2910	0.3660

Table 3.1B Correlation Coefficients of Linear Regression Model of relationship between total fentanyl reports per household and total number of household of people with education level 9th to 12th grade, no diploma.

State	2010	2011	2012	2013	2014	2015	2016
Ohio	0.4172	0.2763	0.1491	0.3767	0.5573	0.5171	0.6744
Pennsylvania	0.5770	0.6575	0.5976	0.5890	0.4127	0.6057	0.7080
Kentucky	0.3682	0.4966	0.2674	0.3638	0.3940	0.4154	0.7968
Virginia	0.1934	0.2646	0.2107	0.7074	0.6642	0.5083	0.7251
West Virginia	-0.0734	0.0104	0.1662	0.3679	0.3162	0.4284	0.5019

Table 3.2B. Correlation Coefficients of Linear Regression Model of relationship between total fentanyl reports per household and total number of household of people with college education, no degree.

State	2010	2011	2012	2013	2014	2015	2016
Ohio	0.4038	0.2632	0.1754	0.3963	0.5858	0.5473	0.7189
Pennsylvania	0.5534	0.6025	0.5803	0.6248	0.6790	0.8045	0.8358
Kentucky	0.3627	0.5238	0.2259	0.4452	0.4501	0.4762	0.8627
Virginia	0.2476	0.3075	0.1867	0.6606	0.6853	0.6599	0.8140
West Virginia	-0.0588	-0.0057	0.0097	0.3881	0.3745	0.4542	0.5793

Table 4B. Correlation Coefficients of Linear Regression Model of relationship between total fentanyl reports per household and total number of household of people who speak English less than "very well".

State	2010	2011	2012	2013	2014	2015	2016
Ohio	0.2564	0.1415	0.1495	0.3987	0.5848	0.5600	0.7132
Pennsylvania	0.5063	0.6205	0.5271	0.6017	0.6640	0.7994	0.8195
Kentucky	0.2727	0.4290	0.2027	0.4553	0.4886	0.5209	0.8964
Virginia	0.2262	0.2553	0.1326	0.7122	0.6819	0.5901	0.7849
West Virginia	-0.0672	-0.0284	0.0020	0.2581	0.2414	0.2822	0.3675

4.3 Evaluation

We use the residual plots to determine whether the regression model is appropriate and reliable (Refer to Graphs and Diagrams, Figure 6 and Figure 7).
The residual plots show that there is a much greater concentration of residual points in fentanyl in the lower left region of all graphs, meaning most of the counties with less than 200,000 people consume less heroin and fentanyl than the mean consumption of the whole state.
We can also see there is a wider and more random spread for the graphs with heroin consumption. Thus, the regression model works much better with heroin consumption per household than fentanyl consumption.

5 Graphs and Diagrams

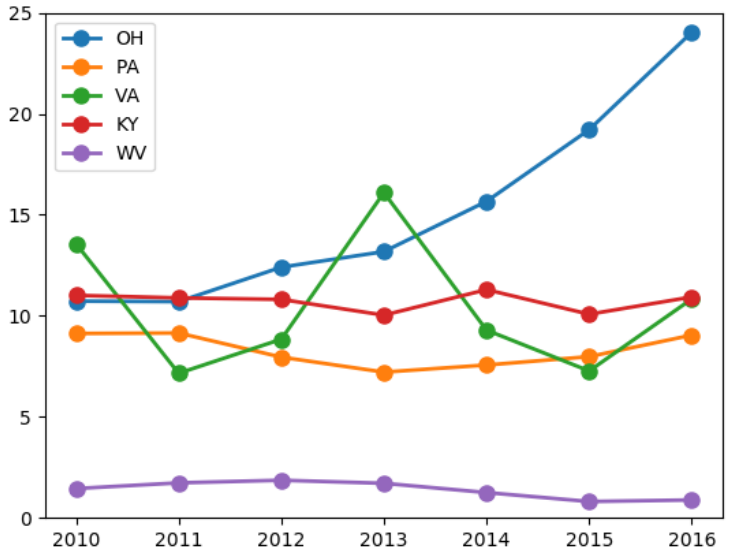

Figure 4: Number of drug reports per house in every state from 2010 to 2016

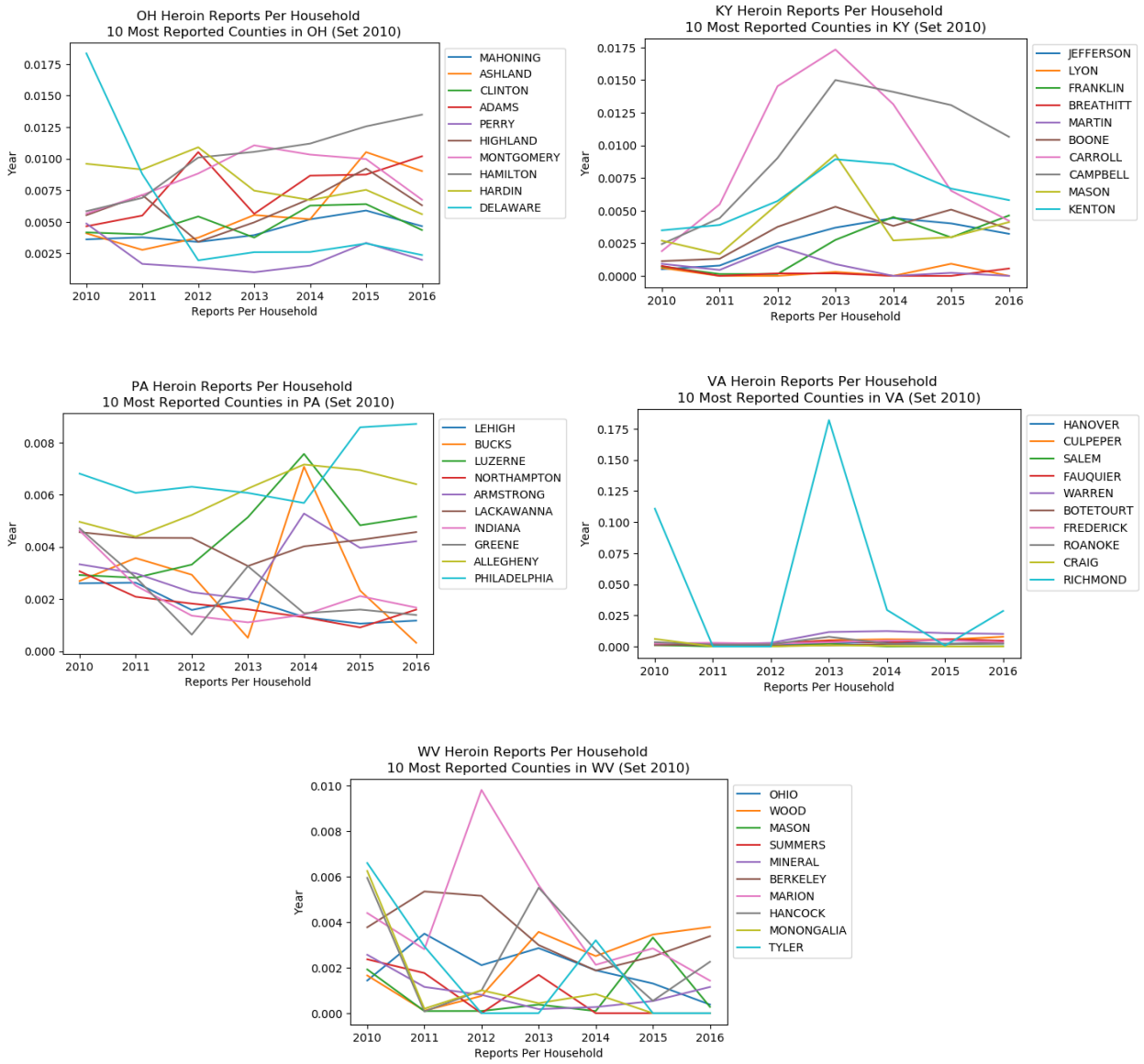

Figure 5: Yearly heroin substance reports per household in state counties with the highest drug reports per household in 2010.

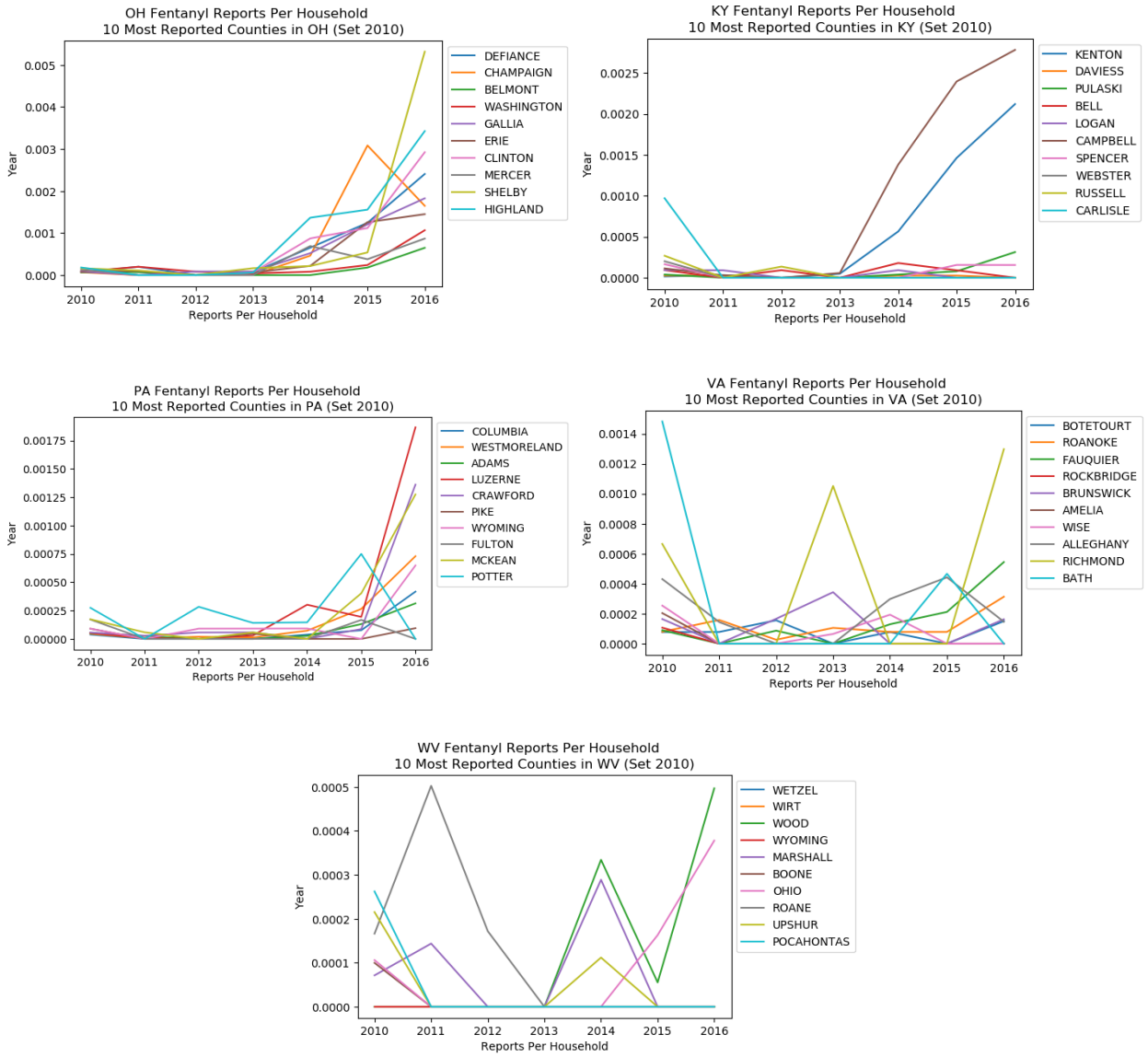

Figure 6: Yearly fentanyl substance reports per household in state counties with the highest drug reports per household in 2010.

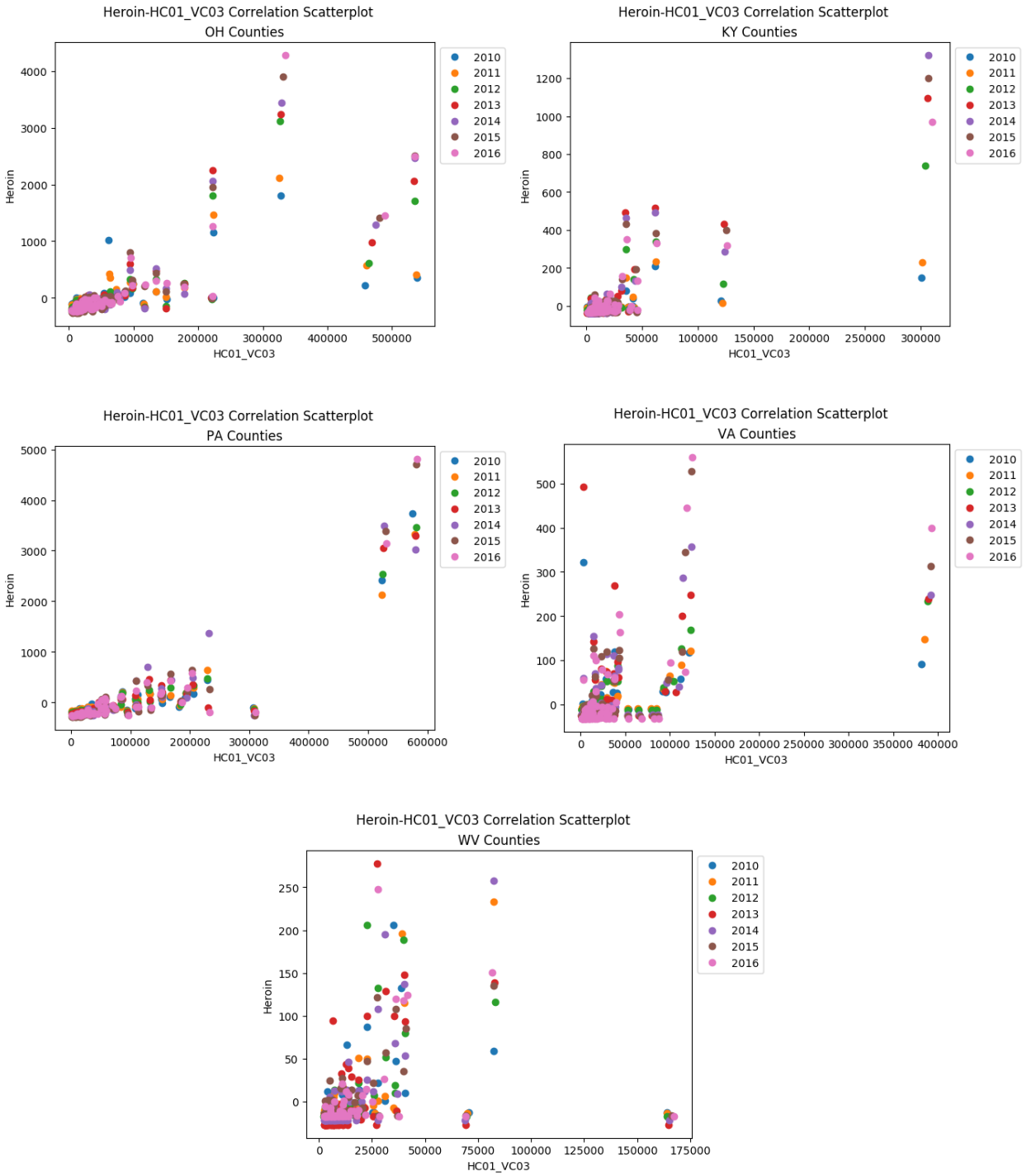

Figure 7: Residuals plots for yearly heroin substance reports per household in state counties in 2010.

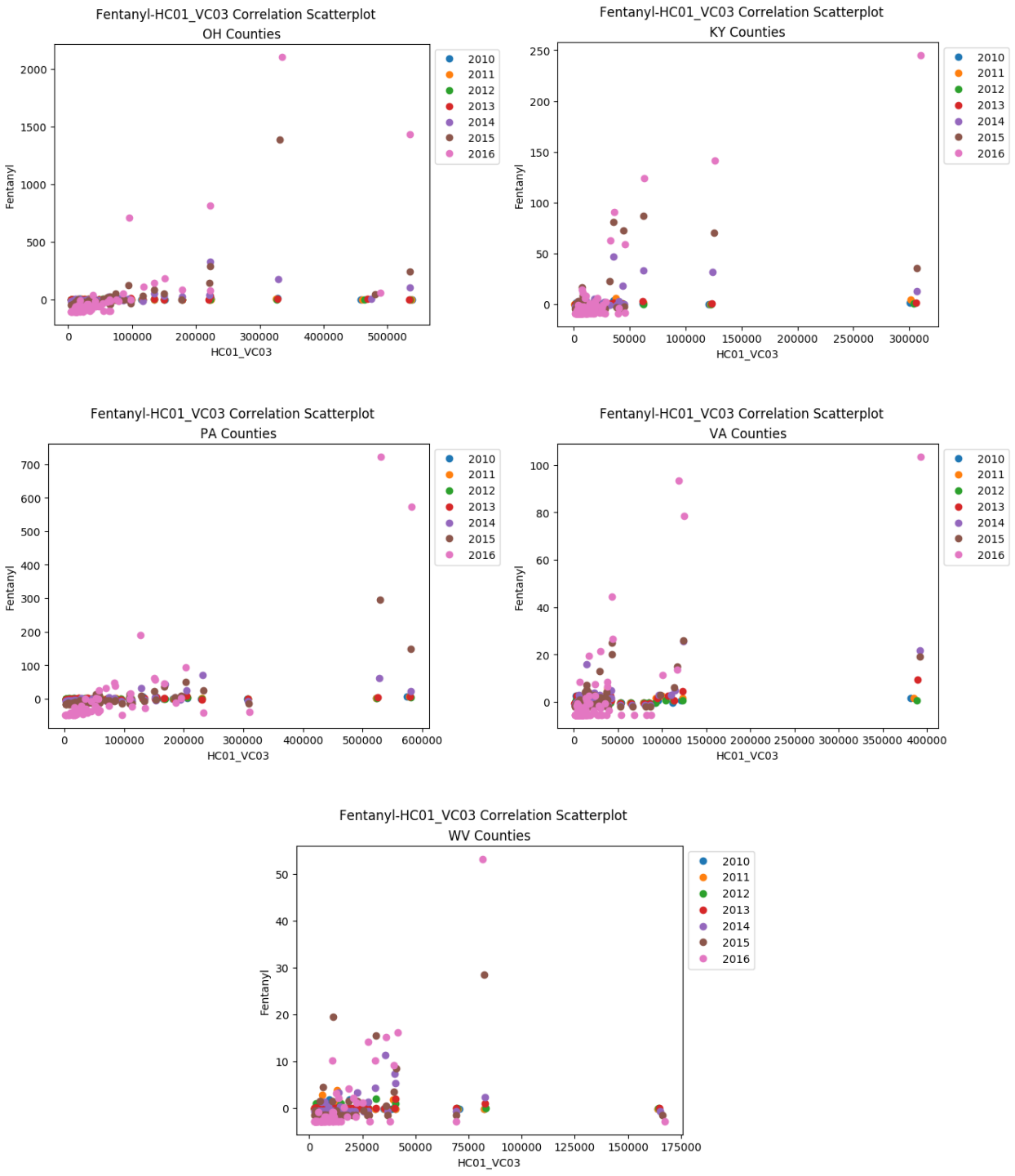

Figure 8: Residuals plots for yearly fentanyl substance reports per household in state counties in 2010.

6 Conclusion

We explored two candidate models for the data on the Opioid Crisis. The first model was the class of growth models: specifically, the exponential growth model and the logistic growth model. The second was a regression model. We drew on sets of data we believed to be related, and studied the correlation coefficients of the scatterplots graphed by the sets of data.

We analyzed our regression models to find correlations between heroin use per household and the total households in states. The correlation was strong in Pennsylvania, weak in Virginia. Furthermore, this correlation increases each year.

For the growth models, we focused on the state of Ohio. Upon a preliminary investigation, we believed the growth rate of Ohio to be exponential. Based on the results of our models, we expect Ohio's number of drug reports to grow continuously in the following years without deceleration.

—Memo to Chief Administrator, DEA/NFLIS Database—

Dear Chief Administrator, DEA/NFLIS Database,

It's our honor for us to propose several models that display the severity of The Opioid Crisis, especially with the recent surge in heroin and synthetic opioid consumption that threatened the growth of the US economy by increasing health care costs. Based on our analysis of the data on the number of drug reports across counties of five states: Ohio, Pennsylvania, Kentucky, Virginia and West Virginia, we identify the top counties in each state regarding drug consumption per household as the sources of drug crisis in each state. To take a closer look at this prevailing problem, we use the exponential and logistic growth models to predict the growth of drug consumption in Ohio, which is most severely hit by the crisis and most likely the source of the crisis in the Middle East-Northeast region.

We also propose the minimum threshold level of drug reports that Ohio will reach if the drug control measures are effective and able to restrict the growth of opioid consumption. We develop the exponential model, which predicts that drug consumption in Ohio will increase at an even faster rate and will never cease growing if the implemented measures do not have a good effect. We present a more hopeful prediction in the form of the logistic model, in which that we predict that total drug reports per household in Ohio will reach a threshold of 50 reports per household in about 6 to 7 years.

We also use regression analysis to analyze the relationship between total drug reports per household and total households of different structures that are at risk of drug addiction (e.g. male or female householder living alone with a child, people with no college degree or high school diploma, people who cannot speak English well).

We find that there is an overall strong positive correlation between the total number of drug reports per household and total households of different structures, meaning that the problem has spread more evenly across all counties for all households above with indicators of socioeconomic status. We believe that the current drug control agencies need to step up and take stronger measures to tackle the problem, such as launching campaigns that will reach out to a much wider audience including people with less than favorable living conditions and no knowledge of alternative pain relievers.

We hope our model demonstrates the urgency of mitigating the crisis and also offers hope that we can overcome this crisis in a near future.

Yours sincerely, Team 1926047

7 References

[1] National Institute on Drug Abuse. "Opioid Overdose Crisis." *NIDA*, 22 Jan. 2019, www.drugabuse.gov/drugs-abuse/opioids/opioid-overdose-crisis.

[2] "Opioid Overdose." *Centers for Disease Control and Prevention*, 19 Dec. 2018, www.cdc.gov/drugoverdose/epidemic/index.html.

[3] Public Affairs. "What Is the U.S. Opioid Epidemic?" *US Department of Health and Human Services*, www.hhs.gov/opioids/about-the-epidemic/index.html.

[4] National Institute on Drug Abuse. "Heroin." *NIDA*, www.drugabuse.gov/drugs-abuse/heroin.

[5] National Institute on Drug Abuse. "Heroin Use Is Driven by Its Low Cost and High Availability." *NIDA*, www.drugabuse.gov/publications/research-reports/relationship-between-prescription-drug-abuse-heroin-use/heroin-use-driven-by-its-low-cost-high-availability.

[6] National Institute on Drug Abuse. "Fentanyl." *NIDA*, 6 June 2016, www.drugabuse.gov/drugs-abuse/fentanyl.

[7] "HEAL Initiative." National Institutes of Health, *U.S. Department of Health and Human Services*, www.nih.gov/research-training/medical-research-initiatives/heal-initiative.

[8] Digital Communications Division. "Better Availability of Overdose-Reversing Drugs." HHS.gov, *US Department of Health and Human Services*, www.hhs.gov/opioids/about-the-epidemic/hhs-response/better-overdose-response/index.html.

[9] Branch, Geographic Products. "County Adjacency File." Census Bureau QuickFacts, *United States Census Bureau*, 1 Sept. 2012, www.census.gov/geo/reference/county-adjacency.html.

[10] NBER, *NBER*, www.nber.org/data/county-adjacency.html.

[11] Fortune Journals. "The Opioid Epidemic: Impact on Children and Families." *Journal of Psychiatry and Psychiatric Disorders, Fortune Journals*, www.jpsychiatrypsychiatricdisord.com/articles/the-opioid-epidemic-impact-on-children-and-families.html.

[12] National Institute on Drug Abuse. "Adolescent Brain." NIDA, 3 Dec. 2015, www.drugabuse.gov/related-topics/adolescent-brain.

[13] "Morbidity and Mortality Weekly Report (MMWR)." *Centers for Disease Control and Prevention*, 17 Aug. 2017, www.cdc.gov/mmwr/volumes/65/wr/mm6533a2.htm.

[14] Abraham, Amanda J et al. "The Affordable Care Act Transformation of Substance Use Disorder Treatment" *American journal of public health* vol. 107,1 (2017): 31-32.

[15] National Academies of Sciences, Engineering, and Medicine; Health and Medicine Division; Board on Health Sciences Policy; Committee on Pain Management and Regulatory Strategies to Address Prescription Opioid Abuse; Phillips JK, Ford MA, Bonnie RJ, editors. Pain Management and the Opioid Epidemic: Balancing Societal and Individual Benefits and Risks of Prescription Opioid Use. Washington (DC): *National Academies Press* (US); 2017 Jul 13. 4, Trends in Opioid Use, Harms, and Treatment. Available from: https://www.ncbi.nlm.nih.gov/books/NBK458661/