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Get the Lead Out: The Connection between Lead and Crime

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It is well known that lead is poisonous. Recent research has shown that lead impacts mammalian neurological systems and impairs specific parts of the brain. Data show that there is a high correlation between environmental lead and crime rates (with an approximately 20-year time lag). This module explores the alleged connection between lead and crime through regression analysis with a time lag, providing an example of environmental racism in communities where race and lead exposure are correlated. We learn that the data support an argument explaining that urban crime is due to environmental lead and conclude that people lower on the socioeconomic ladder are not inherently more violent.

Keywords: environmental racism, lead, crime, regression, time lags

We describe a module that can be used in any course that covers regression with a time lag. The module is short and can be used in class over one to two classes or assigned as a homework project; in either case, we strongly recommend a follow-up class discussion. The time lag of the data is particularly meaningful and important as it demonstrates a correlation between lead exposure in early childhood and crime later in life.

1 Mathematical Content

This module can be used in any statistics course that covers simple linear regression. In order to complete the work, students should be able to graph scatter plots and perform simple linear regression. They should be able to use some form of technology to

complete the regression analysis beyond a calculator such as the TI-83, although it is not impossible to do this with a calculator depending on how instructors use the data provided in Appendix A.

This module builds on simple regression techniques with data that have a correlation with a lengthy time lag. In many cases students skip making scatter plots and just perform the regression analysis, but in this module checking scatter plots is really helpful in understanding and choosing a lag, especially if students are provided with full data sets that need to be trimmed. There is sufficient data provided to perform a number of simple regression analyses as well as data that can be used for multiple regression.

2 Context / Background

Economist Rick Nevin showed that lead exposure, particularly during periods of vulnerability such as before age two, can cause permanent IQ loss and affect behavior [8] [9]. There is a negative correlation between IQ scores and incarceration, and children with higher bone lead levels tend to display more aggressive and delinquent behavior. In other words, consistent exposure to lead at the wrong time is correlated with increased likelihood of negative social outcomes including violent crime and teen pregnancy.

Before 1906, most house paints in the United States contained white lead because it improved the properties of paint (shortened drying time, increased durability, etc.). By the 1920s, the content of white lead in paints began to decline until it was banned for residential use in the United States in 1978. Lead paint still exists in older poorly maintained houses.

Starting in the 1920s, tetraethyl lead was mixed with gasoline to improve engine performance. Cars using leaded gas emit lead in the exhaust which is dispersed into the air and easily inhaled. Leaded fuel use peaked in the early 1970s before it began to be phased out and was finally banned in the United States in 1995.

Given our current understanding of lead on brain development, we may expect that higher environmental lead levels would lead to higher future crime levels. The basic reasoning here is that sufficient lead exposure by preschool children lowers IQ and affects behavior to the extent that later in life these children would be more likely to be involved in crimes. In this module, we look at the relationship between the use of leaded gas and crime rates. We choose to look at this relationship because atmospheric lead dissipates over time, so contact rates can be better estimated.

Following Nevin, we use gasoline lead per 100,000 people as a proxy for the average personal exposure rate to lead. Thus, if car exhaust volume remains constant (that is, emits the same amount of lead) but the population increases, then each person would be exposed to less lead. Similarly, we will compare this to the aggravated assault rate. The papers cited by Nevin are currently available on his website, `http://www.ricknevin.com/` (last accessed on August 28, 2016) along with other background information that instructors may find helpful.

3 Instructor Preparation

It is recommended that instructors analyze the data themselves first and that they review some of the work by Nevin referred to above in Section 2. In particular, one of the central components of this module is the follow-up conversation about race that should take place after the mathematics is done; to prepare for this, instructors should read Nevin's *A Conversation About Race and Crime* [**10**]. It is also recommended that instructors review the notion of environmental racism and look for examples that students at their particular institution will find interesting. For example, the lead issue in the water supply in Flint, Michigan [**4**], might be one such topic. There are also a number of books that one can read for further contextualization of the many factors leading to overrepresentation in the criminal justice system. A possible reference is *The New Jim Crow: Mass Incarceration in the Age of Colorblindness* [**1**].[1]

Instructors should be aware that the topic is sensitive in that it deals with race and crime. Students can easily take home the wrong message that urban residents are more violent and take this as a stereotype for African Americans. This is certainly not the case. The connection between lead and crime can offer an explanation for elevated crime rates in the 1980s and 1990s. More specifically, we want to make sure that students recognize that this particular case of environmental racism suggests that the levels of past urban crime can be attributed to lead poisoning. This rise in crime has subsided and lead has been removed from gasoline for long enough in the U.S. that there is no longer a connection with behavior in general, although there may still be places where lead from paint or other manufacturing sources could be having local impacts. Overall, crime is a complex issue, and lead exposure is an explanation for a particular historical peak. Studying the correlation with lead levels, as one of many possible explanatory factors for the rise and then the fall of violent crime, should not leave students with a simplistic narrative that buttresses negative stereotypes. It might be worth referring to sources such as [**3**] to emphasize how the lead-crime connection has strong explanatory power for the past and that we should not generalize to today's urban youth. We ask instructors to tread carefully and thoughtfully.

4 The Module

4.1 How to use this module. This module can be used either as an in-class activity or it can be assigned as a homework project. If it is used in class, the time it takes will vary depending on the technology skills of the students and how many data sets the instructor chooses to analyze. For example, if the students are comfortable using regression software and the instructor chooses to analyze only one category of crime, then this can be easily done in one 50-minute class. On the other hand, if the instructor chooses to fully analyze all the data provided in Appendix A and includes a multiple regression with crime and unemployment, then this module could take two or three 50-minute classes.

If students have limited access to technology in the classroom then it may be better to assign this project as homework. We provide an example assignment using the

[1] EDITOR'S NOTE: There is a module in this volume by Piercey exploring the arguments in *The New Jim Crow*.

Assault and *Rape* data but we include additional data in Appendix A for further exploration and a richer project. The lags for each are not all the same, and doing this module with a few of the data sets could be valuable. Further, unemployment rates are in the appendix for use with multiple regression, with both gasoline lead rate and unemployment as predictors of crime. Instructors could also choose to provide students with the totals and let them conclude that they need to compare rates. The module is written to provide students with minimal guidance; instructors may choose to provide more explicit directions.

At its simplest, an instructor may use this module by merely providing the students with the given data and asking them to use their knowledge of regression analysis to analyze the relationship between lead and crime. Regardless of whether students get detailed instructions, an important component of this module is the follow-up discussion about correlation and causation, as well as a discussion of environmental racism and the potential impact of lead on African American incarceration rates. Still, even as a basic module, there are many choices an instructor will need to make, starting with a choice of the data.

4.2 Different choices on data. Appendix A contains the gasoline lead data, crime data, U.S. population, and unemployment rates. The gasoline lead data is in metric tons and metric tons per 100,000 people. The crime data consist of *Assault*, *Rape*, *Robbery*, and *All Violent Crime*, as well as rates per 100,000 people. U.S. population data have also been included, as well as the unemployment rates for ages 16-19 and 16-24. Instructors can choose to use just one of the crime data sets, all four, or some select subset. Scatter plots of *Assault*, *Rape*, and *All Violent Crime* exhibit peaks around 1990 and an early peak around 1980 with very consistent patterns, which are very similar to the gasoline lead level data as seen in Figure 7.1.

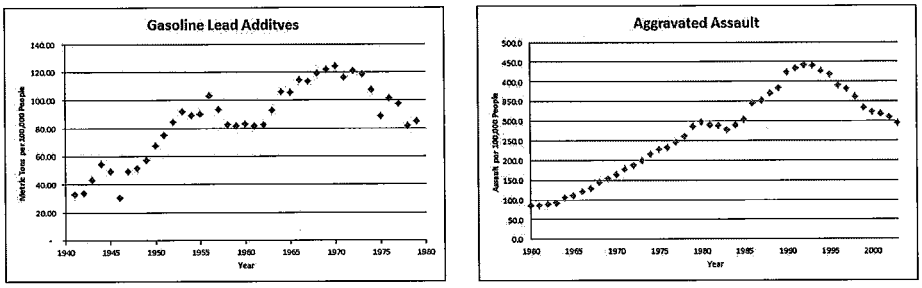

Figure 7.1. Scatter plots of gasoline lead additives and aggravated assault per 100,000 people.

The *Robbery* data have more variation but similar trends. A choice can also be made as to whether or not to provide students with the rate data or just the counts. The U.S. population data were included for those who want to only provide the counts and leave the students to realize they should use rates and then calculate the rates themselves. The scatter plots alone are interesting and could be used early in a course when graphical displays of data are discussed. The plots should be used with the full data sets, but if the choice is made to provide only the data needed for regression, then that is sufficient.

4.3 Other decisions. Instructors can choose how much they want students to investigate different lags. For instance, the best regression fit for *All Violent Crime* and *Lead* is with a 22 year lag. In other words we use the *Violent Crime* data from 1963 through 2001 matching up with the lead data from 1941 through 1979. The lags for *Assault*, *Rape*, and *Robbery*, which produce best fit correlations are 24, 22, and 19 years respectively. For example, Figure 7.2 provides a scatter plot of gasoline lead and aggravated assault with a 24-year lag.

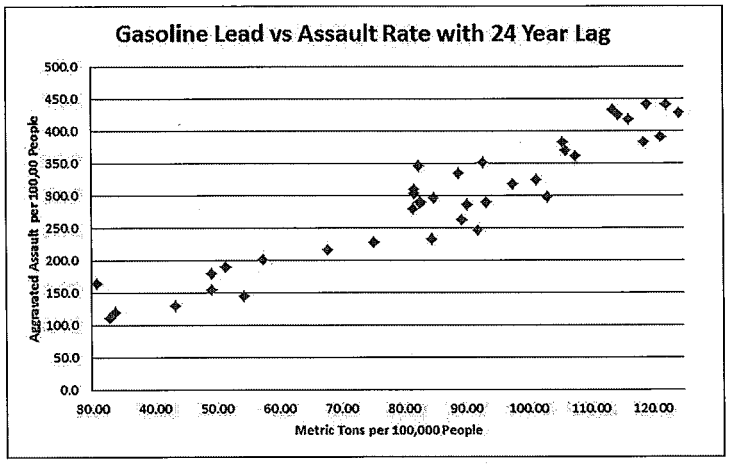

Figure 7.2. Scatter plot of gasoline lead per 100,000 people and aggravated assault per 100,000 people with a 24 year lag.

Enough data have been provided to perform regression with lags from 19 to 24 years. Instructors can choose to provide students with only the data needed for any particular crime variable or provide students with all of the data and test all the lags themselves. The module is likely at its richest when at least two crime variables with different lags are investigated. This should then have students asking why different lags are best for different variables. A rationale for this is given in Nevin [8] where he provides the varying mode and median ages of arrest for different crimes.

One can also choose to include the unemployment data as unemployment is correlated with crime, although the correlation is much weaker (with R^2 values typically about a third of that for the correlation with lead). Still, there is the opportunity to discuss which variable is a better predictor of crime, lead or unemployment. Also, there is the question of whether or not the age 16-19 or the 16-24 data is better and why. The curious student might investigate different lags with the unemployment data and notice that shifting by one or two years provides for better fits. In other words, lagging the unemployment data one year later for *Violent Crime* (1963-2001) with ages 16-19 *Unemployment* (1964-2002) provides a smaller p-value than matching the years. We can only conjecture as to why this might be and we suspect this is due to unemployment being a lagging measure of the economy. In other words, the economy starts to worsen before the unemployment rate increases. Of course, practically speaking, using a predictor variable from the future does not help us predict crime today.

The same data can be used for multiple regression and model building. *Unemployment* and *Lead* are both individually correlated with crime. When used together, lead is still significant (using the lags mentioned above with crime) and the unemployment (no lag) rate yields a p-value of approximately 0.06 for *Rape*, *Robbery*, and *All Violent Crime*, but for *Assault*, it is greater than 0.5. For *Rape*, *Robbery*, and *All Violent Crime* using a two-year lag on unemployment will yield p-values below 0.05. All of this provides for interesting discussion of the best model for predicting violent crime rates.

Lastly, we should note that the results from the appended data do not match Nevin [**8**] exactly. We do not have direct access to his data and had to construct the data sets from their original sources.

4.4 An example assignment. We provide a sample assignment for simple linear regression using two crime variables in Appendix B. The handout can be used as a worksheet for an in-class activity, or it can be the skeleton of the description of a project assignment to be completed out of the classroom.

In this example assignment, we provide students with full data sets and let them decide which variables to use, counts or rates, and let them investigate the lags. If this is used during a class lab, then instructors may want to stop students and make sure they are using rates. If this is a homework project of some type, instructors will need to decide if they want to tell students to use rates or leave them to figure out that they ought to use rates.

We also include two discussion questions at the end to help set up the follow-up conversation that we recommend as a critical part of this module.

4.5 The Follow-Up Conversation. There should be a follow-up conversation after the calculations are complete. The mathematics of this module is fairly routine, but the data and results require careful contextualization.

Discussion should include the environmental justice angle. As noted in Nevin [**8**]:

> *Children in central cities had the greatest exposure to gasoline lead, due to urban traffic congestion, and they realized relatively little benefit from declining levels of lead in paint because older housing units common in central cities had high concentrations of lead in paint from earlier decades. This is particularly true because poorer children have been disproportionately concentrated in central cities, and lower–income households are more likely to have paint in poor conditions, creating paint chip and lead dust hazards. During the years that gasoline lead was used extensively, children exposed to urban atmospheres and to interior lead paint in their homes had about six times higher daily lead intake than suburban children with minimal lead exposure* (U. S. Environmental Protection Agency, 1986).

Nevin further points out in [**10**], "From 1993-2004, the black juvenile homicide arrest rate fell by more than 80%", and "that decline is not explained by changes in the African-American family, poverty, or rising incarceration." The disproportionate incarceration of African-American males could be explained to an extent by the fact that many more of them compared to their white counterparts grew up in inner-cities and poorer housing, thereby have been exposed to more lead.[2]

[2]Nevin in [**10**] makes a distinction between incarcerations due to violent crime and other incarcerations. More specifically, he claims that the numbers for violent crime incarceration are mostly explained by lead exposure, while the remaining numbers may be due to other factors, such as systemic racism.

Is this a form of environmental racism? This depends on whether or not one includes intent as part of the definition. In this case, there is no clear intent to poison so many children in urban areas with lead, since at the time the public did not know the impact of lead on the developing brain. On the other hand, there is still lead paint that needs to be eradicated in older low-income housing, and this issue is not being addressed sufficiently.

The *correlation versus causation* question leads to an important conversation here. The data alone are not sufficient to conclude causations. On the other hand, we do know how lead impacts the developing brain, and this correlation exists not just in U.S. data but also in data from individual cities and other countries. Recent studies show the same correlation with cities that used lead pipes versus those that used iron pipes [7]. There is a case to be made for causation with lead and crime. It should also be pointed out that one cannot run an experiment to conclude that lead exposure increases the chances of criminal activity later in life, for obvious ethical reasons.

Curious students will ask why the crime data stop in 2003. Once the gasoline lead use falls to zero, the correlations start to break down as lead use can no longer be a contributing factor to future crime rates. Crime rates have still been declining but at slower rates. One explanation here is that gasoline lead was a significant driver in the rise and fall of crime rates from about 1960 through 2000, but certainly not the only factor impacting crime rates. What we may be seeing now is a new baseline in crime post-gasoline lead. Finally, there are still children being exposed to lead through lead paint, but this is harder to analyze due to its persistence in the environment.

5 Additional Thoughts

The lead-crime story is an important story to tell. It is a concrete example of unintended consequences of societies' use of a natural substance. At the same time this is also an opportunity to discuss environmental racism, as certain populations, in particular, African Americans in urban areas, have been exposed to disproportionately higher lead levels.

What has been included in this module is mostly the mathematics. There are opportunities for students to investigate the story of lead further, with questions such as;

- *How long did we suspect the dangers of lead before acting?*
- *Why did it take so long to phase out gasoline lead?*
- *How did other countries react?*
- *Is lead still used in gasoline anywhere in the world?*
- *What about lead paint?*

If more regression data are desired, we did not include *Murder*, *Teen Pregnancy*, and *Unwed Pregnancy* variables as used by Nevin [8]. Further papers by Nevin also include data from other countries. The ambitious student could work to collect such data and perform similar analyses.

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[13] USGS, Science for a Changing World. *Bureau of Mines Mineral Yearbook (1932 - 1993).* Available at http://minerals.usgs.gov/minerals/pubs/usbmmyb.html, accessed on August 29, 2016. (For each year, follow *Metals and Minerals* and then *Lead.*)

Appendix A: Tables and Datasets

Table 5.1. U.S. Population (1941 through 1959 [**11**], 1959 through 1979 [**12**]), gasoline lead additives in metric tons and per 100,000 people [**13**]. Gasoline lead is referred to as Tetraethyl Lead or Gasoline Additive under Chemicals depending on the year of the report.

Year	U.S. Population	Gasoline lead additives in metric tons	Gasoline lead additives, metric tons per 100,000 people
1941	133,402,471	43,842	32.86
1942	134,859,553	45,497	33.74
1943	136,739,353	59,257	43.34
1944	138,397,345	75,357	54.45
1945	139,928,165	68,846	49.20
1946	141,388,566	43,513	30.78
1947	144,126,071	71,014	49.27
1948	146,631,302	75,577	51.54
1949	149,188,130	85,860	57.55
1950	152,271,417	103,279	67.83
1951	154,877,889	116,489	75.21
1952	157,552,740	133,105	84.48
1953	160,184,192	147,366	92.00
1954	163,025,854	145,545	89.28
1955	165,931,202	149,806	90.28
1956	168,903,031	174,170	103.12
1957	171,984,130	160,573	93.36
1958	174,881,904	144,616	82.69
1959	177,829,628	145,168	81.63
1960	179,323,175	148,620	82.88
1961	182,992,000	149,506	81.70
1962	185,771,000	153,247	82.49
1963	188,483,000	174,915	92.80
1964	191,141,000	202,707	106.05
1965	193,526,000	204,301	105.57
1966	195,576,000	223,965	114.52
1967	197,457,000	224,229	113.56
1968	199,399,000	237,589	119.15
1969	201,385,000	245,963	122.14
1970	203,235,298	252,656	124.32
1971	206,212,000	239,715	116.25
1972	208,230,000	252,506	121.26
1973	209,851,000	248,941	118.63
1974	211,392,000	227,252	107.50
1975	213,124,000	189,243	88.79
1976	214,659,000	217,505	101.33
1977	216,332,000	211,292	97.67
1978	218,059,000	178,331	81.78
1979	220,099,000	186,945	84.94

Table 5.2. U.S. Population and selected violent crime counts and rates (1960 through 1975 [**5**], 1976 through 1995 [**6**], 1993 through 2003 [**12**]).

Year	U.S. Population	Violent Crime (VC)	VC Rate	Aggravated Assault (AA)	AA Rate
1960	179,323,175	288,460	160.9	154,320	86.1
1961	182,992,000	289,390	158.1	156,760	85.7
1962	185,771,000	301,510	162.3	164,570	88.6
1963	188,483,000	316,970	168.2	174,210	92.4
1964	191,141,000	364,220	190.6	203,050	106.2
1965	193,526,000	387,390	200.2	215,330	111.3
1966	195,576,000	430,180	220.0	235,330	120.3
1967	197,457,000	499,930	253.2	257,160	130.2
1968	199,399,000	595,010	298.4	286,700	143.8
1969	201,385,000	661,870	328.7	311,090	154.5
1970	203,235,298	738,820	363.5	334,970	164.8
1971	206,212,000	816,500	396.0	368,760	178.8
1972	208,230,000	834,900	401.0	393,090	188.8
1973	209,851,000	875,910	417.4	420,650	200.5
1974	211,392,000	974,720	461.1	456,210	215.8
1975	213,124,000	1,026,280	481.5	484,710	227.4
1976	214,659,000	1,004,210	467.8	500,530	233.2
1977	216,332,000	1,029,580	475.9	534,350	247.0
1978	218,059,000	1,085,550	497.8	571,460	262.1
1979	220,099,000	1,208,030	548.9	629,480	286.0
1980	225,349,264	1,344,520	596.6	672,650	298.5
1981	229,146,000	1,361,820	594.3	663,900	289.7
1982	231,534,000	1,322,390	571.1	669,480	289.2
1983	233,981,000	1,258,090	537.7	653,290	279.2
1984	236,158,000	1,273,280	539.2	685,350	290.2
1985	238,740,000	1,328,800	556.6	723,250	302.9
1986	241,077,000	1,489,170	617.7	834,320	346.1
1987	243,400,000	1,484,000	609.7	855,090	351.3
1988	245,807,000	1,566,220	637.2	910,090	370.2
1989	248,239,000	1,646,040	663.1	951,710	383.4
1990	248,709,873	1,820,130	731.8	1,054,860	424.1
1991	252,177,000	1,911,770	758.1	1,092,740	433.3
1992	255,082,000	1,932,270	757.5	1,126,970	441.8
1993	257,782,608	1,926,017	747.1	1,135,607	440.5
1994	260,327,021	1,857,670	713.6	1,113,179	427.6
1995	262,803,276	1,798,792	684.5	1,099,207	418.3
1996	265,228,572	1,688,540	636.6	1,037,049	391.0
1997	267,783,607	1,636,096	611.0	1,023,201	382.1
1998	270,248,003	1,533,887	567.6	976,583	361.4
1999	272,690,813	1,426,044	523.0	911,740	334.3
2000	281,421,906	1,425,486	506.5	911,706	324.0
2001	285,317,559	1,439,480	504.5	909,023	318.6
2002	287,973,924	1,423,677	494.4	891,407	309.5
2003	290,788,976	1,383,676	475.8	859,030	295.4

Table 5.3. Selected violent crime counts and rates (1960 through 1975 [**5**], 1976 through 1995 [**6**], 1993 through 2003 [**12**]) and seasonally adjusted unemployment rates for ages 16-19 and 16-24 [**2**].

Year	Robbery (R)	R Rate	Forcible Rape (FR)	FR Rate	Unemployment Rate Ages 16-24	Unemployment Rate Ages 16-19
1960	107,840	60.1	17,190	9.6	11.3	14.7
1961	106,670	58.3	17,220	9.4	13.0	16.8
1962	110,860	59.7	17,550	9.4	11.4	14.8
1963	116,470	61.8	17,650	9.4	12.2	17.2
1964	130,390	68.2	21,420	11.2	11.5	16.2
1965	138,690	71.7	23,410	12.1	10.2	15.0
1966	157,990	80.8	25,820	13.2	8.5	12.7
1967	202,910	102.8	27,620	14.0	8.7	12.9
1968	262,840	131.8	31,670	15.9	8.6	12.5
1969	298,850	148.4	37,170	18.5	8.4	12.2
1970	349,860	172.1	37,990	18.7	11.1	15.3
1971	387,700	188.0	42,260	20.5	12.8	16.9
1972	376,290	180.7	46,850	22.5	12.1	16.3
1973	384,220	183.1	51,400	24.5	10.5	14.5
1974	442,400	209.3	55,400	26.2	11.9	16.0
1975	464,970	218.2	56,090	26.3	16.1	20.0
1976	427,810	199.3	57,080	26.6	14.7	19.0
1977	412,610	190.7	63,500	29.4	13.6	17.8
1978	426,930	195.8	67,610	31.0	12.2	16.4
1979	480,700	218.4	76,390	34.7	11.8	16.1
1980	565,840	251.1	82,990	36.8	13.9	17.8
1981	592,910	258.7	82,500	36.0	14.9	19.6
1982	553,130	238.9	78,770	34.0	17.8	23.2
1983	506,570	216.5	78,920	33.7	17.2	22.4
1984	485,010	205.4	84,230	35.7	13.9	18.9
1985	497,870	208.5	88,670	37.1	13.6	18.6
1986	542,780	225.1	91,460	37.9	13.3	18.4
1987	517,700	212.7	91,110	37.4	12.2	16.9
1988	542,970	220.9	92,490	37.6	11.0	15.3
1989	578,330	233.0	94,500	38.1	10.9	15.1
1990	639,270	257.0	102,560	41.2	11.2	15.6
1991	687,730	272.7	106,590	42.3	13.5	18.7
1992	672,480	263.6	109,060	42.8	14.2	20.2
1993	659,870	256.0	106,014	41.1	13.4	19.1
1994	618,949	237.8	102,216	39.3	12.4	17.6
1995	580,509	220.9	97,470	37.1	12.1	17.4
1996	535,594	201.9	96,252	36.3	12.0	16.7
1997	498,534	186.2	96,153	35.9	11.3	16.0
1998	447,186	165.5	93,144	34.5	10.4	14.6
1999	409,371	150.1	89,411	32.8	9.9	14.0
2000	408,016	145.0	90,178	32.0	9.3	13.1
2001	423,557	148.5	90,863	31.8	10.6	14.8
2002	420,806	146.1	95,235	33.1	12.0	16.5
2003	414,235	142.5	93,883	32.3	12.4	17.4

Appendix B: Assignments and Handouts

A Worksheet on Lead and Crime

Background. Lead exposure, especially at the preschool age, can lead to neurological development problems including lower IQ and behavioral issues. Children with higher blood lead levels are more likely to commit crimes when they are older [**8**]. This project looks at gasoline lead use and crimes such as aggravated assault rates to address the main question:

> IS THERE A RELATIONSHIP BETWEEN GASOLINE LEAD USE AND AGGRAVATED ASSAULTS AND / OR RAPE?

Questions.

(1) You have been provided with data on lead gasoline consumption, lead gasoline consumption per 100,000 people, U.S. population, total number of aggravated assaults, the aggravated assault rate per 100,000 people, total number of rapes and rapes per 100,000 people. Which variables should be used to try and answer the main question? Why did you choose those variables?

(2) Create scatter plots of the variables you will use with time as the independent variable for each. How do the graphs compare?

(3) Create scatter plots to help address the main question. What lag did you use and why? How should you decide if it is the best choice?

(4) Find the least squares regression line, using a lag with the best R^2 value. Provide a response to the main question including all the information your regression analysis provided.

(5) Is this correlation or causation? If you say correlation, then could it be causation?

(6) Are there populations within the U.S. that would have been more or less affected by lead emissions from cars? Why or why not?