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**Abstract**  
Abstract: The objective of the research reported in this paper was to assess the health impacts and economic costs of particulate pollution caused by woodsmoke from domestic heating in a rural town. Using a survey of general practitioners (GPs), the number of respiratory cases per day was related to the level of particulate (PM2.5) pollution. Poisson regression was used, with the number of GP visits for respiratory treatment the dependent variable and level of pollution, temperature and the location of the GP surgery as explanatory variables. This provided an estimate of the number of cases caused by woodsmoke pollution. The economic cost was then obtained by multiplying this number of cases by the cost per patient. The results show that particulate air pollution caused by woodsmoke from domestic heating does result in patients presenting with respiratory illness. Approximately 38% of total respiratory visits to GP surgeries were due to particulate air pollution. The daily economic cost of respiratory symptoms in the town due to this pollution was estimated to be $1666. The work has two major implications. First, it presents a method of using GP data to estimate the level of morbidity and cost associated with particulate air pollution. Second, it shows that there is a need in rural towns to consider the health impacts of planning decisions related to wood heating.

**Call Number:** CSU278517
ECONOMIC COST OF PARTICULATE AIR POLLUTION IN ARMYDALE: CLINICAL EVENT SURVEY

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Economic Cost of Particulate Air Pollution in Armidale: Clinical Event Survey

Abstract

Objective: To assess the health impacts and economic costs of particulate pollution caused by woodsmoke from domestic heating in a rural town, and to suggest appropriate remedial action.
Method: Using a survey of GPs, the number of respiratory cases per day was related to the level of particulate (PM2.5) pollution. Poisson regression was used, with the number of GP visits for respiratory treatment the dependent variable and level of pollution, temperature and the location of the GP Clinic as explanatory variables. This provided an estimate of the number of cases caused by woodsmoke pollution. The economic cost was then obtained by multiplying this number of cases by the cost per patient.

Results: Approximately 13 per cent of total respiratory visits to GP clinics were due to particulate air pollution. The daily economic cost of respiratory symptoms in the town due to this pollution was estimated to

Conclusion: Particulate air pollution caused by woodsmoke from domestic heating does result in patients presenting with respiratory illness. The cost to the community of this illness can be assessed.

Implications: Council regulations in rural towns need to be aware of the health impacts of planning decisions related to wood heating. There is a clear case to consider policies that encourage the replacement of wood burning as a source of domestic heating.
Objectives

The convergence of epidemiological results suggests a clear role of particulates, especially fine particulates, in triggering a number of adverse health effects including increased rate of lower respiratory symptoms, upper respiratory symptoms, increased hospital admissions, increased emergency room visits, asthma attacks, a decrease in lung function and increased mortality.\textsuperscript{1, 2, 3, 4, 5, 6}

The health effects of particulate pollution have been associated with different particulate size fractions. Small particles, such as those from fossil fuel combustion, are likely to be the most dangerous, because they can be inhaled deeply into the lungs, settling in areas where the body’s natural clearance mechanisms are unable to remove them.\textsuperscript{7} There is no threshold concentration of either PM10 or PM2.5 below which adverse health effects have not been observed.\textsuperscript{8, 9, 10, 11, 12}

Woodsmoke consists almost entirely of fine particles (PM2.5). Emissions from domestic wood heaters are an increasing and potential harmful source of air pollution in Australia. The adverse health effects of woodsmoke pollution have been studied in the US and other countries,\textsuperscript{7} but despite substantial quantities of pollution generated by wood burning, little research has been carried out in Australia.

Armidale, located in Northern New South Wales, Australia, is an ideal place to examine the potential health effects of woodsmoke, since air pollution in Armidale consists almost entirely of emissions from wood heaters. Low temperatures in winter, together with relatively cheap wood fuel, encourage people to burn wood for space heating. As much as two tonnes of particulates can be emitted into the air over Armidale on a very cold night.\textsuperscript{13, 14} Incomplete combustion results in increased quantities of pollutants, which become trapped in Armidale's frequent temperature inversions.
The study examined whether there is any relationship between particulate air pollution and the number of patients with respiratory symptoms visiting local general practitioners' clinics. The main objective of the study was to estimate the effects of particulate air pollution in Armidale in terms of health status and economic cost. The public health implications are then assessed.

**Method**

Many studies have used data such as hospital admission or emergency room visits to examine respiratory morbidity.\textsuperscript{15,16,17} However, hospital data require large populations in order to identify relationships between air pollution and respiratory illness. Because Armidale is a small town (population 22,000), it was more appropriate to use local GP data to identify such a relationship.

There are both direct and indirect links between lower temperatures and increases in respiratory illnesses. Temperature certainly plays a primary role in the generation of particulate air pollution, since low temperatures encourage people to light up their wood heaters, leading to increased particulate pollution. Lower temperatures may also directly trigger an increase in respiratory illness or asthma attacks.

The day of the week may also be important in establishing the pattern of respiratory consultations, since GP clinics are closed on weekends. Any increase in respiratory patients in GP clinics may, in part, be confounded by a “weekend effect”. In particular, we could expect increases on Mondays and Fridays. Further, the location of GP clinics might have an important influence on increases in respiratory patient visits. Figure 1 shows the impact of temperature on particulate pollution causing physical effects and which incur economic costs.

Thus, the factors: minimum temperature, particulate air pollution, location of the GP clinic and day of the week were incorporated as conditional variables in the model for examining clinical events. The essential feature of the analysis in this paper is the decomposition of the total number of respiratory patients into those caused by air pollution and those due to all other causes. The estimated number due to air pollution is then multiplied by the estimated cost.
Data

Particulate Air Pollution and Weather Data
Particulate air pollution data for the winter of 1999 (June to August) were obtained from the Armidale Air Quality Group (AAQG), the Armidale Dumaresq Council (ADC) and the Environmental Protection Authority (EPA), NSW. The Armidale Air Quality Group’s data were measured in the East Armidale residential area. The City Council Nephelometer readings were taken at the council chamber in the CBD area, which is a relatively chimney-free area. Usually the air pollution reading at ADC is about half the AAQG’s reading. Air pollution data were collected for both the daily (24-hours) mean concentration and daily maximum (1-hour) concentration.

Weather data for Armidale were obtained from the Bureau of Meteorology-NSW regional office. The Bureau of Meteorology station is located at the Armidale Airport, 1084m above sea level and at the western end of the valley. The Bureau station records minimum, maximum, dew point and average daily temperatures, wind speed, wind vector speed and wind direction at 20-minute intervals.

Respiratory Symptoms Data
Respiratory symptom data were collected from Armidale General Practitioner (GP) Clinics. There are a total of 26 GPs in Armidale, practising in 8 clinics in the city. The number of GPs per clinic varies from 1 to 6 with some working only part-time. A total of 15 general practitioners from 6 clinics were willing to participate.

The GPs recorded the diagnoses observing the following classification (a) total visits (respiratory and non-respiratory) for that day; (b) respiratory visits due to acute upper respiratory symptoms; (c) respiratory visits due to acute lower respiratory symptoms; (d) respiratory visits due to chronic lower respiratory symptoms; (e) visits due to asthma; and
(f) visits due to respiratory infection. For each day the number of medical visits with each diagnosis was totalled across clinics.

Data were collected during the period 1 June to 20 August, a total 12 weeks, excluding weekends.

In the study period, the total number of patients was 9,481 of whom 1,370 persons presented with respiratory illness, which was 14.4 per cent of the total number of GP visits. Table 1 provides the general descriptive statistics of the study sample period from June 1999 to August 1999.

Results

Particulate air pollution was found to be negatively related to temperature, which supports the proposition that the wood used for heating was an important source. Also there was a fairly strong correlation between Armidale Air Quality Group and Armidale Dumaresq Council data.

The Pairwise Pearson correlation coefficient was calculated for the total number of respiratory patients and air pollution and the proportion of respiratory patients and air pollution. Pollution data included same day, 1-day lag, 2-day lag, 3-day lag and 4-day lag. Only particulate pollution 2-day lagged was consistently associated with both proportion of respiratory visits and total number of respiratory visits to the local GP clinics. Table 2 shows the correlation between respiratory visits and air pollution.

Total respiratory visits were found to be significantly correlated with 2-day lagged air pollution levels. The proportion of respiratory visits was also correlated with 2-day lagged particulate air pollution.
The preliminary regression analysis, which included particulate air pollution, temperature, location of clinic and day of the week, indicated that the day of the week effects were not significant. A formal test of the coefficients of the day of the week variables confirmed this. The final result, discussed below, shows significant associations between particulate air pollution (PM2.5) and occurrence of respiratory symptoms requiring a GP’s attention within the population in Armidale (with two-day lag).

Initial analysis also indicates that there was little variation in the results obtained by using different sources of air pollution data. Therefore, only the set of data reflecting the mean of average daily air pollution recorded by Armidale Air Quality Group (AAQG) and Armidale Dumaresq Council (ADC) has been considered in the model to assess the economic cost.

**Analytical Method-Poisson Regression**

In conventional regression analysis, we have a *continuous* (dependent) variable and we seek to explain its variation. This is done by postulating that the value the variable takes is determined to a large extent by some other (regressor) variables. The regression model shows how the average of the dependent variable is determined by the values of regressor variables. Poisson regression is the analogous statistical tool for the analysis of *count data*.

In this context, the variable we seek to explain is the number of patients per day who visit clinics with respiratory complaints. We assume that this number is determined, in part, by the value of particulate air pollution, the minimum temperature, and the particular clinic chosen. Variables that measure these three types of determinants become the regressor variables, denoted collectively by $X$. The average number of respiratory patients, denoted as $n_r$, is the dependent variable.

The Poisson regression model relates the dependent variable to the regressor variables through the function

$$n_r = \exp(X'\beta) \quad (1)$$

where $\exp(.)$ is the exponential function, and $X'\beta$ is a linear combination of the regressor variables. In particular, we assume that
\[ X'\beta = \beta_0 + \beta_1 x + \delta_1 C_1 + \ldots + \delta_5 C_5 + \varphi_0 T + \varphi_1 T_1 + \ldots + \varphi_4 T_4, \tag{2} \]

where \( x \) is particulate air pollution lagged 2 days, \( C_1 \) to \( C_5 \) are dummy variables relating to the five clinics other than the base clinic (clinic 0), \( T \) is the minimum temperature and \( T_1 \) to \( T_4 \) are the minimum temperatures lagged one to 4 days, respectively.

Poisson regression results, giving estimates of the unknowns \( \beta_0 \) to \( \varphi_4 \), are shown in Table 3.

In interpreting the results, two features should be noted. First, the coefficient in which we are mainly interested is \( \beta_1 \), associated with air pollution \( (x) \). Its value of 0.00693 means that a one unit increase in air pollution, with all other factors unchanged, leads to a 0.693 per cent increase in the number of respiratory patients. Alternatively, a one standard deviation (21.12 units) increase in air pollution results in a \( 21.12 \times 0.693 = 14.6 \) per cent increase.

Second suppose, for example, we are interested in the average number of respiratory patients attending clinic 5 on a day in which air pollution is 24 units, the minimum temperature 2 degree Celsius and has been for the last 4 days. In this example, the variables in the model have the following values:

\[ x = 24, C_1 = C_2 = C_3 = C_4 = 0, C_5 = 1, T = T_1 = T_2 = T_3 = T_4 = 2 \]

Thus,

\[ n_r = \exp[1.187 + (0.00693) \times 24 + (0.0145) \times 2 + (-0.0029) \times 2 + (0.0076) \times 2 + (0.0012) \times 2 + (0.0235) \times 2 + (-0.4957) \times 1] \]

\[ = \exp(0.9454) \]

ie: \( n_r = 2.574 \) patients

and so the average number of respiratory patients at clinic 5 on all days with these characteristics is 2.57.

In exactly the same way, the model can be used to estimate the average number of respiratory patients for any combination of values of air pollution, clinic and minimum daily temperature.

To estimate the costs due to air pollution, we now use the model to decompose \( n_r \) into a part due to air pollution, and the remainder accounting for all other causes of respiratory illness.

First, we write \( X'\beta \), defined by equation 2 as
\[ X'\beta = a + b + c \]

where

\[
\begin{align*}
    a &= \beta_1 x \\
    b &= \beta_0 + \delta_1 C_1 + \ldots + \delta_5 C_5, \\
    c &= \phi_0 T + \phi_1 T_1 + \ldots + \phi_4 T_4.
\end{align*}
\]

Note that “a” is determined by the value of air pollution alone, “b” by the particular clinic and “c” by the minimum temperatures.

Then,

\[ n_r = \exp(a + b + c) = \exp(a) \ast \exp(b) \ast \exp(c). \]

Also, because the absolute values of “a” and “c” are small relative to 1 for all values of the variables, we can approximate \( \exp(a) \) and \( \exp(c) \) by \((1 + a)\) and \((1 + c)\), respectively. Thus, \( n_r \) can be approximated by

\[ n_r = \exp(b) \ast (1 + a) \ast (1 + c) = \exp(b) \ast (a + 1 + c), \]

because \((a \ast c)\) is always small enough to be ignored. Thus, finally,

\[ n_r = n_{r,x} + n_{r,o} \]

where \( n_{r,x} \) is that component of \( n_r \) attributable to air pollution alone, given by

\[ n_{r,x} = a(\exp(b)) = \beta_1 x \exp(\beta_0 + \delta_1 C_1 + \ldots + \delta_5 C_5). \quad (3) \]

To assist in the interpretation of (3), we define \( n^{(i)}_{r,x} \) to be the contribution to \( n_{r,x} \) due to the \( i \)th clinic.

Then

\[ n^{(i)}_{r,x} = \beta_1 x \exp(\beta_0 + \delta_i) \quad (4) \]

where \( i = 0,1,2,\ldots,5 \)

and \( \delta_0 = 0. \)

There is one final factor that we must account for in order to estimate the number of pollution-caused respiratory patients. In most of the six clinics surveyed, only some of the doctors completed
the survey. We therefore apply “expansion factors” \( a_i \) which adjust the values of \( n^{(i)}_{r,x} \) to take this into account. For example, in clinic 2 only 2 of the 5 doctors actually completed the survey. We therefore adjust \( n^{(i)}_{r,x} \) for this clinic by multiplying by \( a_2 = 5/2 = 2.5 \).

Finally, we define the estimated average number of pollution induced respiratory patients at clinic \( i \), denoted by \( N^{(i)}_{r,x} \), as

\[
N^{(i)}_{r,x} = a_i \ n^{(i)}_{r,x} = a_i \beta_1 x \exp(\beta_0 + \delta_i)
\]  

(5)

The method for computing the number of pollution-caused respiratory patients per day for the whole of Armidale, for any given value of air-pollution \( x \), is simply to add the contributions for each clinic. For example, for clinic 2 with adjustment factor \( a_2 = 2.5 \), we obtain

\[
N^{(2)}_{r,x} = 2.5 \beta_1 x \exp(\beta_0 + \delta_2) = 2.5 \ (0.006933) \ x \exp(1.187 + 0.01884)
\]

\[
= 2.5(0.023153)x = 0.05788x.
\]

We note that the above expression is linear in \( x \) (the value of air pollution). It follows that over time, the average number of pollution-caused respiratory patients can be obtained by replacing \( x \) by its average value, namely \( \bar{x} = 22.9 \). Thus, the daily average at clinic 2 = \( (0.05788)*(22.9) = 1.325 \) patients. This computation was carried out for each clinic, and the average daily number of respiratory patients (for the survey period) at the six clinics which can be attributed to air-pollution is thus \( N_{r,x} = 7.45 \) persons.

**Standard Error of the Estimate**

Denoting the vector of estimated coefficients collectively by \( \beta \), the standard error of \( N_{r,x} \) is given by

\[
\text{se} \ (N_{r,x}) = \bar{x} \sqrt{\sum \left( \frac{\partial N_{r,x}}{\partial \beta'} \right) \left( \frac{\partial N_{r,x}}{\partial \beta} \right) \text{cov}(\beta)}
\]

(6)

where \( \text{cov}(\beta) \) is the covariance matrix of \( \beta \). Using the covariance matrix which accompanies the Poisson regression output, this expression can be evaluated to obtain

\[
\text{se} \ (N_{r,x}) = 1.52
\]
**Economic Cost**

To assess the economic cost, only doctors’ fees, costs of medicine and wage losses are considered.

Typically, general practitioners in Armidale charge, on average, $40 per visit (New England Division of General Practice). Allowing for transport costs and medical prescription, a rough estimate of an additional $50 per consultation seems reasonable.

We assume that each visit takes one half day of an adult’s time and that such time is valued at $61 based on the national annual wage rate for Australia (ABS 2000). While not every one who seeks medical attention due to respiratory symptoms will miss half a day of work, the wage rate is considered a good reflection of the average value of time for this population. Some patients are children who do not earn wages, however all visits for children include adult supervision, with a consequent potential wage loss.

Therefore, the total cost for each respiratory visit is estimated as

\[
40 + 50 + 61 = 151
\]

The average daily cost of pollution induced respiratory illness (for the survey period) is now obtained by multiplying the average number of respiratory patients \(N_{r,s}\) by the cost of a respiratory visit. That is,

\[
\text{Average daily cost} = 151 \times 7.45 = 1125.
\]

The standard error of this cost estimate is \(151 \times 1.52 = 229\)

**Discussion and Limitations of Findings**

The result of the analysis suggests there was an association between respiratory-related GP visits and particulate air pollution in Armidale.

**Major Findings**

i. During the survey period, the average number of respiratory patients due to particulate air pollution in Armidale was 7.45 persons.
ii. Approximately 13 per cent of the total respiratory visits to local GP clinics were due to particulate air pollution.

iii. Taking into consideration the costs and expenses arising from such ailments, the average daily economic cost of respiratory symptoms due to particulate air pollution was estimated to be $1,125.

The estimated economic cost is conservative, and it only considers the direct medical costs. Dollar outlays were calculated in terms of doctors’ usual charge for clinic visits, cost of drugs, and time loss estimated on the basis of the average wage rate. Related costs, such as X-rays, hospital admission, emergency room visits, alternative medicines and so on, and costs associated with “pain and suffering” have been ignored. Furthermore, data were only available from six of the eight GP clinics, resulting in underestimation of the true effects.

Conceptually, the monetary aspect could be extended further. One important step would be to estimate the value of missed schooling and work loss. Contingent valuation techniques might yield estimates of willingness to pay by the people of Armidale for the value of “pain and suffering” due to respiratory symptoms.

The study did not take account of preventive or defensive measures, which could contribute to an underestimation of economic cost. For example, asthma can be controlled with maintenance treatment. Many asthma patients experience mild symptoms and treat themselves with medication instead of reporting to a GP. Such cases are not captured in the GP reports. Asthma also affects people chronically, and the estimate only captures exacerbation due to fluctuations in pollution levels.

As the clinical survey was based on respiratory visits to local GPs, the study excluded hospital admission and emergency room visits. Patients with severe asthma attacks, who normally go to the hospital emergency department rather than to clinics, have not been included. In many cases, asthma imposes significant costs on persons with symptoms and their families. Researchers have used the cost-of-illness method to estimate the direct and indirect costs of asthma prevalence for several developed economies, including the US, Canada and the UK. Barnes et al. tabulated summary measures from nine studies in which direct costs typically contributed 50 to 60 per cent of total costs.¹⁸
In one of the earlier studies assessing the economic costs of air pollution, Ransom and Pope, compared hospital admissions and mortality data before and after the temporary closure of a steel mill in a mountain valley in central Utah.¹⁹ They estimated that the annual increase in hospitalisation costs were US$2 million and more than US$40 million in mortality costs, due to particulate emissions.

Zaim estimated that by reducing its air pollution to WHO levels from 1993, Turkey would have reduced hospital admissions for respiratory diseases by 5,480, emergency room visits by 112,100, avoided 6.85 million restricted activity days and 73,000 cases of low respiratory symptoms in children 0-12 years of age. The estimated annual economic value of avoiding these effects represented nearly 0.08 per cent of Turkey’s 1993 gross national product.²⁰

Hall et al. predicted that hypothetical attainment of air pollution standards in the Californian south coast air basin would save 1,600 lives a year. However, the benefits of actual attainment were not known.²¹

It is clear from the above that inclusion of emergency room visits, hospital admissions and mortality would substantially increase the economic cost of particulate air pollution in Armidale.

**Implications of Findings**

The findings from this study have several implications. One is that an improvement in air quality from a reduction in woodsmoke particulate pollution in Armidale can lead to both health and economic benefits to society. The economic cost estimated in this study was limited by the available data and should be regarded only as providing a lower bound. If additional data on hospital admissions, emergency room visits, willingness to pay and so on were available, a more realistic assessment of economic costs could be obtained. In terms of public health, there is a clear case to consider policies that encourage the replacement of wood burning as a source of domestic heating. Indeed, supported by the EPA, the Armidale City Council has adopted a policy of providing incentives to householders for the removal of wood heaters.

**Reference:**


Table 1: Summary Statistics: Air Pollution and Temperature Data
1 June to 20 August, 1999

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Minimum Temperature</td>
<td>0.98</td>
<td>4.48</td>
<td>-8.00</td>
<td>9.00</td>
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<tr>
<td>Daily average particulate pollution (AAQG) PM2.5</td>
<td>31.82</td>
<td>31.39</td>
<td>1.71</td>
<td>140.46</td>
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<tr>
<td>Daily average particulate pollution (ADC) PM2.5</td>
<td>13.93</td>
<td>12.14</td>
<td>1.26</td>
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<td>Daily maximum particulate pollution (AAQG) PM2.5</td>
<td>96.18</td>
<td>83.76</td>
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<td>Daily maximum particulate pollution (ADC) PM2.5</td>
<td>46.08</td>
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<td>186.75</td>
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<td>Daily average particulate pollution (ADC +AAQG) PM2.5</td>
<td>22.90</td>
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<td>Daily maximum particulate pollution (ADC +AAQG) PM2.5</td>
<td>21.13</td>
<td>61.32</td>
<td>3.17</td>
<td>215.91</td>
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</tbody>
</table>

AAQG= Armidale Air Quality Group, ADC= Armidale Dumaresq Council

Table 2: Correlation Between Respiratory Visits and Air Pollution

<table>
<thead>
<tr>
<th></th>
<th>Proportion of respiratory visits</th>
<th>Total number of visits</th>
</tr>
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<tbody>
<tr>
<td>Ave.AAQG-2-day lag</td>
<td>0.227 (.000)</td>
<td>0.252 (.000)</td>
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<tr>
<td>Max.AAQG, 2-day lag</td>
<td>0.192 (.001)</td>
<td>0.222 (.000)</td>
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<tr>
<td>Ave.ADC, 2-day lag</td>
<td>0.208 (.000)</td>
<td>0.207 (.000)</td>
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<tr>
<td>Max.ADC, 2-day lag</td>
<td>0.163 (.005)</td>
<td>0.142 (.015)</td>
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<tr>
<td>Ave.(AAQG+ADC), 2-day lag</td>
<td>0.299 (.000)</td>
<td>0.248 (.000)</td>
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<tr>
<td>Max.(AAQG+ADC), 2-day lag</td>
<td>0.191 (.001)</td>
<td>0.206 (.000)</td>
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</table>

* Figure in parentheses indicates p values

Table 3: Results of the Estimated Poisson Regression

<table>
<thead>
<tr>
<th>Variables</th>
<th>Estimated Coefficient</th>
<th>Standard Error</th>
<th>p-Value</th>
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<td>.0017534828</td>
<td>.0001</td>
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<td>T</td>
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<td>.010993110</td>
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<tr>
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**Figure 1: Links and Some Key Variables**

![Figure 1: Links and Some Key Variables](image-url)