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

Lutfa Khan[1], Kevin Parton[2] and Howard Doran[3]

[1]Department of State Development, Queensland Government,
[2]School of Rural Management, Charles Sturt University &
[3]School of Economics, University of New England

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 ($PM_{2.5}$) 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.

Key words: *Pollution; Woodsmoke; Wood Heaters; Rural Town; Public Health Implications*

The convergence of epidemiological results suggests a clear role of particulates, especially fine particulates (less than 2.5 microns in aerodynamic diameter), in triggering a number of adverse health effects. These include increased rates of lower respiratory symptoms, upper respiratory symptoms, asthma attacks, a decrease in lung function; and increased mortality. There is often a consequent increase in the use of health care services typically measured by hospital admissions or emergency room visits (Abramson & Beer 1998; Dockery et al.1993; Ostro 1987; Ostro & Rothschild 1989; Pope & Dockery 2006; Pope et al.1995). As well as such short-term impacts, longer-term health effects such as an increase in cardiovascular disease have been observed (Künzli et al. 2005).

The health effects of particulate pollution have been associated with different particulate size fractions. Fine particulates, such as those from fossil fuel combustion, are likely to be the most hazardous, because they are inhaled deep into the lungs, settling in areas where the body's natural clearance mechanisms are unable to remove them (Larson & Koening 1994). The National Environment Protection Council (NEPC) has defined National Environment Protection Measures (NEPMs) for PM_{10} and $PM_{2.5}$ particulates (NEPC 2003), but no threshold concentration of either PM_{10} or $PM_{2.5}$ below which cases would not occur has been observed. Detrimental health effects have been observed at low levels of concentration (Baruch 1998; Morgan et al. 2003; Pearce & Crowards 1996; Samoli et al. 2005; Schwartz et al. 1994; World Health Organization [WHO] 1995).

Woodsmoke consists almost entirely of fine particles ($PM_{2.5}$). Emissions from domestic wood heaters are a potential harmful source of air pollution in Australia. The adverse health effects of woodsmoke pollution have been studied in the United States (US) and other countries (Larson & Koening 1994), but despite substantial quantities of pollution generated by wood burning, little research into the health effects has been carried out in Australia (New South Wales Department of Health 2003).

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 (Roberts & Lin 1998). Low temperatures in winter, together with relatively cheap wood fuel, encourage people to operate wood heaters. As much as two tonnes of particulates can be emitted into the air over Armidale on a very cold night (Armidale Dumaresq Council [ADC] 2003; Wall 1997). Incomplete combustion results in increased quantities of pollutants, which become trapped in Armidale's frequent temperature inversions.

This study examined whether there is a relationship between particulate air pollution and the number of patients with respiratory symptoms visiting local GPs' surgeries. 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. Based on this information the public health implications are then assessed.

Method

Overall approach

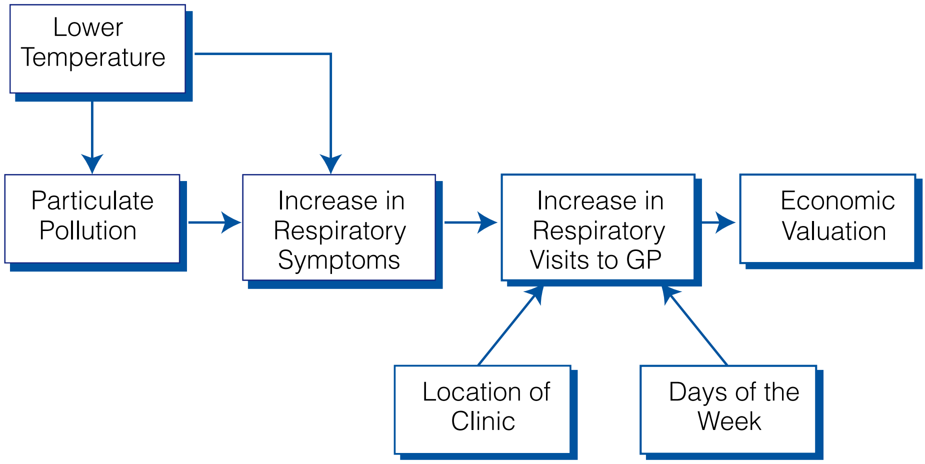
The method adopted was to estimate the statistical relationship between number of respiratory cases (the dependent variable) and pollution, minimum temperature and surgery location (the explanatory variables). The morbidity data were measured as GP visits. These data were collected from GP surgeries. The $PM_{2.5}$ particulate pollution data were collected from nephelometer readings by the Armidale Air Quality Group (AAQG) and the ADC, and the weather data were provided by the Bureau of Meteorology.

Many studies have used data such as hospital admission or emergency room visits to examine respiratory morbidity (Ponka et al. 1991; Pope 1989, 1991). 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. GP data might also be usefully employed in an urban setting.

There are direct and indirect links between lower temperatures and increases in respiratory illnesses (Diaz et al. 2004). Temperature certainly plays a primary role in the generation of particulate air pollution, since low temperatures encourage people to use their wood heaters, leading to increased particulate pollution. Lower temperatures might also directly trigger an increase in respiratory illness or asthma attacks (Diaz et al. 2004; Verlato 2002; Weiland et al. 2004). This might mean that heating, even using a wood heater, could provide health benefits to some individuals.

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

Figure 1: A schematic outline of the key variables



Thus, the factors of minimum temperature, particulate air pollution, location of the GP surgery and day of the week, were incorporated as explanatory variables in the model for examining clinical events. The essential feature of the analysis in this paper is the disaggregation 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 was then multiplied by the estimated cost.

The analytical method was Poisson regression (Fleiss et al. 2003). 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 (or explanatory) 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 surgeries 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 surgery 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:

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

where exp(.) is the exponential function, and $X'\beta$ is a linear combination of the regressor variables (Fleiss et al. 2003). In particular, we assume that

$$X'\beta = \beta_0 + \beta_1 x + \delta_1 C_1 + \ldots + \delta_5 C_5 + \varphi_0 T + \varphi_1 T_1 + \ldots + \varphi_4 T_4, \qquad (2)$$

where x is particulate air pollution lagged 2 days, C_1 to C_5 are dummy variables relating to the five surgeries other than the base surgery (surgery 0), T is the minimum temperature and T_1 to T_4 are the minimum temperatures lagged one to 4 days, respectively. The model of equation 2 was then used to summarise the impact of $PM_{2.5}$ particulate pollution and weather on the number of respiratory cases.

Respiratory symptoms data

Respiratory symptom data were collected from Armidale General Practitioner Surgeries. There is a total of 26 GPs in Armidale, practising in eight surgeries in the city. The number of GPs per surgery varies from 1 to 6 with some working only part-time. All 26 GPs were contacted, and 15 GPs from six surgeries agreed to participate in the study.

The GPs were asked to record 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 surgeries. Data were collected during the period 1 June to 20 August, a total of 12 weeks, excluding weekends.

In the study period, a total of 9481 patients were seen by the GPs, of whom 1370 persons presented with respiratory illness, which was 14.4% of the total number of GP visits.

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) and the ADC. The data from the AAQG's data were measured in the East Armidale residential area. The ADC nephelometer readings were taken at the council chamber in the Central Business District (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. The AAQG used a Radiance Research Reeve Analytical Orthogonal nephelometer calibrated for $PM_{2.5}$, and a conversion ratio of one scattering coefficient unit to 20 µg/m^3 of $PM_{2.5}$ was applied (Robinson et al. 1998). As explained below, this became our principal source of pollution data.

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, about five kilometres from the CBD. The weather variable of interest in the present study was minimum temperature. As discussed above this was expected to impact directly on the number of respiratory cases, and indirectly though its impact on the

Table 1: Summary statistics: Air pollution and temperature data 1 June to 20 August 1999

	Mean	Std. deviation	Minimum	Maximum
Daily Minimum temperature (°C)	0.98	4.48	-8.00	9.00
Daily average particulate pollution (AAQG) $PM_{2.5}$ (µg/m^3)	31.82	31.39	1.71	140.46
Daily average particulate pollution (ADC) $PM_{2.5}$ (µg/m^3)	13.93	12.14	1.26	44.82
Daily maximum particulate pollution (AAQG) $PM_{2.5}$ (µg/m^3)	96.18	83.76	3.17	325.94
Daily maximum particulate pollution (ADC) $PM_{2.5}$ (µg/m^3)	46.08	44.50	2.25	186.75
Daily average particulate pollution (ADC +AAQG) $PM_{2.5}$ (µg/m^3)	22.90	21.21	1.98	86.77
Daily maximum particulate pollution (ADC +AAQG) $PM_{2.5}$ (µg/m^3)	21.13	61.32	3.17	215.91

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

Table 2: Correlation between respiratory visits and air pollution

	Proportion of respiratory visits	Total number of visits
Ave.AAQG-2-day lag	0.227 (.000)	0.252 (.000)
Max.AAQG, 2-day lag	0.192 (.001)	0.222 (.000)
Ave.ADC, 2-day lag	0.208 (.000)	0.207 (.000)
Max.ADC, 2-day lag	0.163 (.005)	0.142 (.015)
Ave.(AAQG+ADC), 2-day lag	0.299 (.000)	0.248 (.000)
Max.(AAQG+ADC), 2-day lag	0.191 (.001)	0.206 (.000)

amount of wood burning and hence $PM_{2.5}$ levels. Table 1 provides the general descriptive statistics of the 12-week study period.

Results & Discussion

Initial results

Particulate air pollution was found to be negatively related to temperature, which supports the proposition that wood was an important source of heating. The strong correlation between AAQG and ADC data (correlation coefficient = 0.86), indicated that one or other should be used in the regression analysis, but not both as this would introduce a multicollinearity problem. Given its nephelometer location in a residential area, the AAQG data source was considered the more appropriate to use.

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 surgeries. Table 2 shows the correlation between respiratory visits and air pollution. These correlations are significantly different from zero. Together with the plausible lag of two days between particulate pollution event and presentation at the surgery, they support the conclusion that the numbers of respiratory visits to the GP surgeries was directly related to the ambient level of $PM_{2.5}$ 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 surgery and day of the week, indicated that the day of the week effects were not significant. A formal test

Table 3: Results of the estimated Poisson regression

Variables	Estimated Coefficient	Standard Error	p-Value
X	.0069	.0017	.0001
T	.0144	.0079	.0680
T_1	-.0028	.0109	.7934
T_2	.0076	.0091	.4033
T_3	.0012	.0081	.8790
T_4	.0234	.0080	.0036
C_1	.7603	.0826	.0000
C_2	.0188	.0980	.8475
C_3	.2577	.0823	.0017
C_4	-.1112	.1103	.3134
C_5	-.4957	.1232	.0001
Constant	1.1869	.0854	.0000

of the coefficients of the day of the week variables confirmed this. The final result, discussed below, shows significant associations between particulate air pollution ($PM_{2.5}$) and occurrence of respiratory symptoms requiring a GP's attention within the population in Armidale (with two-day lag).

Poisson regression results

Poisson regression results, giving estimates of the unknowns β_0 to φ_4, are shown in Table 3. The level of $PM_{2.5}$ pollution (X) is a significant influence (p<0.001) on number of respiratory cases presenting at GP surgeries.

In interpreting the results, two features should be noted. First, the coefficient in which we are mainly interested is β_1, associated with air pollution (x). Its value of 0.00693 means that an increase in $PM_{2.5}$ of 1µg/m^3, with all other factors unchanged, leads to a 0.693% increase in the number of respiratory patients. Alternatively, a one standard deviation (21.12 µg/m^3 of $PM_{2.5}$) increase in air pollution results in a 21.12 x 0.693 = 14.6% increase.

Second, suppose, for example, we are interested in the average number of respiratory patients attending surgery number 5 on a day in which air pollution is 24µg/m^3 of $PM_{2.5}$, and the minimum temperature is 2° 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, by putting these values into the equation of Table 3, the resulting expected number of respiratory cases at surgery 5 is 2.574 patients.

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

= exp(0.9454)

i.e.: n_r = 2.574 patients

and so the average number of respiratory patients at surgery number 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, surgery and minimum daily temperature.

To estimate the costs due to air pollution, we now use the model to disaggregate n_r into a part due to air pollution, with the remainder accounting for all other causes of respiratory illness.

First, we re-write equation 2 as:

$$X'\beta = a + b + c \qquad (2a)$$

where

$a = \beta_1 x$

$b = \beta_0 + \delta_1 C_1 + \ldots + \delta_5 C_5$,

$c = \varphi_0 T + \varphi_1 T_1 + \ldots + \varphi_4 T_4$.

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

Then,

$n_r = \exp(a + b + c) = \exp(a)^* \exp(b)^* \exp(c)$.

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

$n_r = \exp(b)^* (1 + a)^* (1 + c) = \exp(b)^* (a + 1 + c)$,

because (a * 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

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

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

Then

$$n^{(i)}_{r,x} = \beta_1 x \exp(\beta_0 + \delta_i) \qquad (4)$$

where i = 0,1,2,...,5

and $\delta_0 = 0$.

There are two factors that must be accounted for in order to estimate the number of pollution-caused respiratory patients in Armidale. The first is to obtain a better estimate of the number of patients at each surgery and the second is to aggregate to the city level. In most of the six surgeries surveyed, only some of the doctors completed the survey. We therefore apply 'expansion factors' α_i which adjust the values of $n^{(i)}{}_{r,x}$ to take this into account. For example, in surgery 2 only 2 of the 5 doctors actually completed the survey. We therefore adjust $n^{(i)}{}_{r,x}$ for this surgery by multiplying by α_2 = 5/2 = 2.5. Then to move to the aggregate city-level estimate a second factor γ = 26/22 =1.18 was applied to express the shift from the six represented surgeries with 22 GPs to the eight surgeries in the city with 26 GPs. Such an adjustment procedure is appropriate because the underlying regression model is linear (Hill et al. 2001). It makes the assumption that the case load of each GP is approximately the same.

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

$$= N^{(i)}{}_{r,x} = \alpha_i n^{(i)}{}_{r,x} = \alpha_1 \beta_1 x \exp(\beta_0 + \delta_i) \quad (5)$$

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 surgery and apply the factor γ (=1.18). For example, for surgery 2 with adjustment factor α_2= 2.5, we obtain

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

$$= 2.5(0.023153)x = 0.05788x.$$

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 for this surgery can be obtained by replacing x by its average value, namely $\bar{x}$= 22.9. Thus, the daily average at surgery 2 = (0.05788)*(22.9) = 1.325 patients. This computation was carried out for each surgery, and the average daily number of respiratory patients (for the survey period) at the six surgeries which can be attributed to air-pollution is thus $N_{r,x}$= 7.45 persons. Then this is multiplied by γ = 1.18 to obtain 8.80 persons as the estimate for Armidale.

To estimate the proportion of these respiratory cases caused by $PM_{2.5}$ particulate air pollution we take the total number of respiratory cases reported by the GPs (=1370) and find the average per day, noting that there were 59 working days during the study period. This is 23.22. Thus the proportion related to $PM_{2.5}$ particulate air pollution is 37.9%.

Denoting the vector of estimated coefficients collectively by β, the standard error of $N_{r,x}$ is given by

$$\text{se}\,(N_{r,x}) = \gamma \bar{x}\ \frac{\partial N_{r,x}}{\partial \beta'} \text{cov}(\beta) \frac{\partial N_{r,x}}{\partial \beta} \qquad (6\,)$$

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

se ($N_{r,x}$) = 1.79

Economic cost

To assess the economic cost, only the cost of morbidity, as measured by the sum of doctors' fees, costs of medicine and wage losses, is considered. The cost of mortality was not included in this study because the sample size is too small to give a meaningful estimate. Moreover, if deaths had been recorded during the survey and included in the estimate of economic cost, it could have given a significant bias to the estimate. Elsewhere, Khan (2003) provides an estimate of this theoretical expected mortality cost in the study context as $6.4 million.

In our initial discussions with the New England Division of General Practice the figure of $35 was suggested as the average charge per visit. The GPs in the survey charged various fees from zero to $55. The mean was close to $40 per visit. Indexing this cost by changes in the CPI between December 1999 and March 2007 (Australian Bureau of Statistics [ABS] various dates) gives approximately $50.15 in 2007 terms. Doctors were asked to estimate their patients' costs for prescriptions and transport. The average prescription cost per patient was about $45 and, although more difficult to estimate, the average travel cost was about $5. Allowing for transport costs and medical prescription,a rough estimate of an additional $50 per consultation seemed reasonable. Indexing this cost by changes in the CPI gives approximately $62.70 in 2007 terms.

We assume that each visit takes one half day of an adult's time and that such time was valued at $61 based on the national annual wage rate for Australia (ABS 2000). Again indexing this by changes in the CPI gives about $76.50. While not everyone 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

$50.15 + $62.70 +76.50 = $189.35

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

Average daily cost = $189.35 x 8.80 = $1,666.28.

The standard error of this cost estimate is $189.35 x 1.79 = $338.94.

Discussion and Limitations of Findings

The result of both the correlation and regression analysis shows that there was an association between respiratory-related GP visits and particulate air pollution in Armidale.

Major findings

There are three main findings from the study.

i. During the survey period, the average number of respiratory patients due to particulate air pollution in Armidale was 8.80 persons/day.

ii. Approximately 38% 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 $1666.

The estimated economic cost is conservative, and it only considers the direct medical costs. Dollar outlays were calculated in terms of GPs' usual charge for surgery 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', and mortality have been ignored.

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 (Karimzadegan et al. 2007) 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 surgeries, 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 United Kingdom (UK). Barnes et al. (1996) tabulated summary measures from nine studies in which direct costs typically contributed 50 to 60% of total costs.

In one of the earlier studies assessing the economic costs of air pollution, Ransom and Pope (1992), compared hospital admissions and mortality data before and after the temporary closure of a steel mill in a mountain valley in central Utah. They estimated that the annual increase in hospitalisation costs was US$2 million and more than US$40 million in mortality costs, due to particulate emissions.

Zaim (1997) estimated that by reducing its air pollution to WHO levels from 1993, Turkey would have reduced annual hospital admissions for respiratory diseases by 5480, annual emergency room visits by 112,100, avoided 6.85 million restricted activity days per year and 73,000 cases per year of low respiratory symptoms in children 0-12 years of age. The estimated annual economic value of avoiding these effects represented nearly 0.08% of Turkey's 1993 gross national product.

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

Conclusion

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 Dumaresq City Council has adopted a policy of providing incentives to householders for the removal of wood heaters.

References

Abramson, M. & Beer, T. 1998, 'Something particular in the air we breathe?', Editorials, *Medical Journal of Australia*, vol. 169, pp. 452-3.

Australian Bureau of Statistics (ABS) 2000, *Average Weekly Earnings, States and Australia*, ABS, Canberra.

Australian Bureau of Statistics (ABS) various dates, *Consumer Price Index*, ABS, Canberra.

Armidale Dumaresq Council (ADC) 2003, *Final Report, Woodsmoke Reduction Program*, Armidale Dumaresq Council Planning and Environmental Services Division.

Barnes, P.J., Honsson, B. & Klim, J.B. 1996, 'The cost of asthma', *European Respiratory Journal*, vol. 9, pp. 636-42.

Baruch, R. 1998, 'The health effects from air pollution: Results of Sydney studies', in *Particulate Pollution in Australian Rural Towns*, ed. K.A. Parton, Centre for Health Research and Development, University of New England, Armidale.

Diaz, J., Linares, C., Garcia-Herrera, R., Lopez, C. & Trigo, R. 2004, 'Impact of Temperature and Air Pollution on the Mortality of Children in Madrid', *Journal of Occupational & Environmental Medicine*, vol. 46, no. 8, pp. 768-774.

Dockery, D.W., Pope, C.A., Xu, X., Spengler, J.D., Ware, J.H., Fay, M.A., Ferris, B.G. & Speizer, F.E. 1993, 'An association between air pollution and mortality in six US cities', *New England Journal of Medicine*, vol. 329, no. 24, pp.1753-9.

Fleiss, J.L., Levin, B., & Paik, M.C. 2003, *Statistical Methods for Rates and Proportions*, Wiley, Hoboken, N.J.

Hill, R.C., Griffiths, W.E. & Judge, G.G. 2001, *Undergraduate econometrics*, 2nd edn, Wiley, New York.

Karimzadegan, H., Rahmatian, M., Farhood, D. & Yunesian, M. 2007, 'Economic valuation of premature mortality and morbidity', *International Journal of Environmental Research*, vol. 1, no. 2, pp. 128-35.

Khan, L. 2003, Particulate air pollution in Armidale, unpublished PhD thesis, University of New England, Armidale.

Künzli, N., Jerrett, M., Mack, W.J., Beckerman, B., LaBree, L., Gilliland, F., Thomas, D., Peters, J. & Hodis, H.N. 2005. 'Ambient air pollution and atherosclerosis in Los Angeles', *Environmental Health Perspectives*, vol. 113, no. 2, pp. 201-6.

Larson, T.V. & Koenig, J.Q. 1994. 'Wood smoke: Emissions and noncancer respiratory effects', *Annual Review of Public Health*, vol. 15, pp. 133-56.

Morgan, G., Lincoln, D., Sheppeard, V., Jalaludn, B., Beard, J. F., Simpson, R., Petroeschevsky, A., O'Farrell, T. & Corbett, S. 2003, 'The effects of low level air pollution on daily mortality and hospital admissions in Sydney, Australia, 1994 to 2000: ISEE-571', *Epidemiology*, vol. 14, no. 5 (Suppl.), pp. S111-S112.

National Environment Protection Council (NEPC) 2003, *Variation to the National Environment Protection (Ambient Air Quality) Measure*, National Environment Protection Council, Adelaide.

New South Wales Department of Health 2003, *Wood Smoke from Wood-fired Home Heaters*, Publication No. 030199, North Sydney, NSW.

Ostro, B.D. 1987, 'Air pollution and morbidity revisited: A specification test', *Journal of Environmental Economics and Management*, vol. 14, pp. 87-98.

Ostro, B.D. & Rothschild S. 1989, 'Air pollution and acute respiratory morbidity: An observation study of multiple pollutants', *Environmental Research*, vol. 50, pp. 238-47.

Pearce, D. & Crowards, T. 1996. 'Particulate matter and human health in the United Kingdom', *Energy Policy*, vol. 24, no. 7, pp. 609-19.

Ponka, A. 1991. 'Asthma and low level air pollution in Helsinki', *Archives of Environmental Health*, vol. 46, no. 5, pp. 262-9.

Pope, C.A. 1989, 'Respiratory disease associated with community air pollution and a steel mill, Utah Valley', *American Journal of Public Health*, vol. 79, no. 5, pp. 623-8.

Pope, C.A. 1991, 'Respiratory hospital admissions associated with PM_{10} pollution in Utah, Salt Lake, and Cache Valleys', *Archives of Environmental Health*, vol. 46, no. 2, pp. 90-7.

Pope, C.A., Thun, M.J., Namboodiri, M.M., Dockery, D.W., Evans, J.S., Speizer, F.E. & Heath, C.W. 1995, 'Particulate air pollution as a predictor of mortality in a prospective study of US adults', *American Journal of Respiratory & Critical Care Medicine*, vol. 151, pp. 669-74.

Pope, C.A. & Dockery, D.W. 2006, 'Health effects of fine particulate air pollution: Lines that connect', *Journal of the Air and Waste Management Association*, vol. 56, pp. 709-42.

Ransom, M.R. & Pope, C.A. 1992, 'Elementary school absences and PM_{10} pollution in Utah Valley', *Environmental Research*, vol. 58, pp. 204-19.

Roberts, G. & Lin, J. 1998, 'Armidale woodsmoke issue: NSW EPA approach', in *Particulate Pollution in Australian Rural Towns*, ed. K.A. Parton, Centre for Health Research and Development, University of New England, Armidale.

Robinson D.L., Monro J., Campbell E.A. & Gras J.L. 1998, Air pollution from domestic heating and health, in *Particulate Pollution in Australian Rural Towns*, ed, K.A. Parton, Centre for Health Research and Development, University of New England, Armidale.

Samoli, E., Analitis, A., Touloumi, G., Schwartz, J., Anderson, H.R., Sunyer, J., Bisanti, L., Zmirou, D., Vonk, J.M., Pekkanen, J, Goodman, P., Paldy, A., Schindler, C. & Katsouyanni, K. 2005, 'Estimating the exposure-response relationships between particulate matter and mortality within the APHEA multicity project', *Environmental Health Perspectives*, vol. 113, no. 1, pp. 88-95.

Schwartz, J., Dockery, D.W., Neas, L.M., Wypij, D., Wane J.H., Spengler, J.D., Koutrakis, P., Spiezer, F.E. & Ferris, B.G. 1994. 'Acute effects of summer air pollution on respiratory symptoms reported in children', *American Journal of Respiratory and Critical Care Medicine*, vol. 15, pp. 1234-42.

Verlato, G., Calabrese, R. & De Marco, R. 2002, 'Correlation between asthma and climate in the European Community Respiratory Health Survey', *Archives of Environmental Health*, vol. 57, no. 1, pp. 48-52.

Wall, J. 1997, Sustainability of the Armidale Fuel Wood Industry on the Northern Tablelands of New South Wales: Resource Yield, Supply and Demand and Management Options, Unpublished PhD Thesis, University of New England, Armidale.

Weiland, S.K., Hüsing, A., Strachan, D.P., Rzehak, P., Pearce, N. & the ISAAC Phase One Study Group 2004, 'Climate and the prevalence of symptoms of asthma, allergic rhinitis, and atopic eczema in children', *Occupational and Environmental Medicine*, vol. 61, pp. 609-15.

World Health Organization (WHO) 1995, *Update and Revision of the Air Quality Guidelines for Europe 'Classical' Air Pollutant*, WHO Regional Office, Copenhagen.

Zaim, K.K. 1997, 'Estimation of health and economic benefits of air pollution abatement for Turkey in 1990 and 1993', *Energy Policy*, vol. 25, no. 13, pp.1093-7.

Correspondence to:
Kevin Parton
Charles Sturt University
PO Box 883
Orange, NSW, 2800
AUSTRALIA
Email: kparton@CSU.edu.au