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Reducing the healthcare costs of urban air pollution: The South African experience

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Abstract

Air pollutants often have adverse effects on human health. This paper investigates and ranks a set of policy and technological interventions intended to reduce such health costs in the high population density areas of South Africa. It initially uses a simple benefit–cost rule, later extended to capture sectoral employment impacts. Although the focus of state air quality legislation is on industrial pollutants, the most efficient interventions were found to be at household level. These included such low-cost interventions as training householders to place kindling above rather than below the coal in a fireplace and insulating roofs. The first non-household policies to emerge involved vehicle fuels and technologies. Most proposed industrial interventions failed a simple cost–benefit test. The paper's policy messages are that interventions should begin with households and that further industry controls are not yet justifiable in their present forms as these relate to the health care costs of such interventions.

Keywords: Air pollution; Economic efficiency; Marginal abatement cost; Cost-effectiveness; South Africa; Health care costs

1. Introduction

This paper emerged from a document presented to South Africa's Nedlac policy forum.[1] The occasion of the discussion was a proposed new air quality bill. Members of the forum were concerned about the broad economic implications of more stringent air quality control measures.

South Africa has an urbanising population, many of whom live in the high-density townships that surround the major centres. In these areas both industry and households are responsible for air emissions that may be locally severe. A number of initiatives are underway to reduce levels of harmful air pollutants. These include a new Air Quality bill before Parliament, a draft report on possibilities for environmental taxation and the review of existing emissions standards.

"Dirty fuels" are major contributors to urban air pollution in South Africa, and a local debate has developed about the relative merits of alternative approaches to the problem: regulating their use; phasing them out; cleaning their emissions; and intervening to reduce their impacts.

The theory of environmental externalities describes a single 'pollutant' whose effects can be abated (Baumol and Oates, 1988; Cropper and Oates, 1992). Each successive attempt to cut the emission is more expensive than the preceding one, and there are assumed to be diminishing returns to the benefits of abatement. Reality is however often more challenging than theory. In reality geography, demography and chemistry all play their parts. The damage done by a given atmospheric emission will typically be influenced by the smoke stack height, wind direction and wind velocity, amongst others. The implications from a policy perspective are profound: the "ideal" air quality targets, and the interventions needed to attain

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[1] Nedlac is a forum where government, business, labour and community organisations meet to discuss social and economic policy.

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them, are likely to be far more elusive goals in the real world than naive theory implies. In this study the problem was circumvented by identifying a set of pollution-abating activities and ranking these in order of the present value of the marginal net benefit (MNB) each offered. The study was bounded by focussing only on the associated health care costs of air pollution in urban areas.

Section 2 of the paper presents the economic background to the problem and discusses the South African Clean Air Initiatives. Section 3 describes the methodology of the study and Section 4 presents its results. The paper also points out some surprising findings of the study that may be of policy relevance elsewhere in the developing world.

2. Economic issues in pollution reduction and The South African clean air initiative

The environmental externalities approaches to pollution control describe an optimal level of abatement. This optimum is reached when the private cost of abating an incremental unit of the pollutant equals the incremental damage done by it (see Fig. 1). Marginal abatement cost is typically shown as an increasing function of the emissions level; the first unit is the cheapest to abate and costs per unit of abatement increase thereafter. Uncertainty about the optimal policy response is often presented as the consequence of strategic incentives that induce polluters to overstate the costs of abatement (Pearce and Turner, 1990, pp. 89–91; Perman et al., 1999, pp. 217–219).

The result is a simple and clear cut optimal level of abatement (or if preferred, optimal level of pollution). Fig. 1 presents an example of the standard diagrammatic presentation.

As abatement (which commences from the right of the diagram) proceeds, its MNB falls, reaching zero when total emissions have been driven down to level E^*. Marginal abatement benefits (MAB) reflect the external (and private) health costs avoided when emissions are reduced. When emissions have fallen to E^*, abating emissions by one unit adds as much to costs as it yields in private and social benefits (i.e. MAB = MAC). Abatement expenditures are therefore justifiable economically whenever the ambient level of pollution (or the emission from a point source) exceeds E^*. In reality policy makers are unlikely to target an optimal ambient pollutant level immediately, but to initiate iteratively those actions or technologies expected to reduce emissions towards the ideal. Their decision concerns the order in which these initiatives are to be adopted.

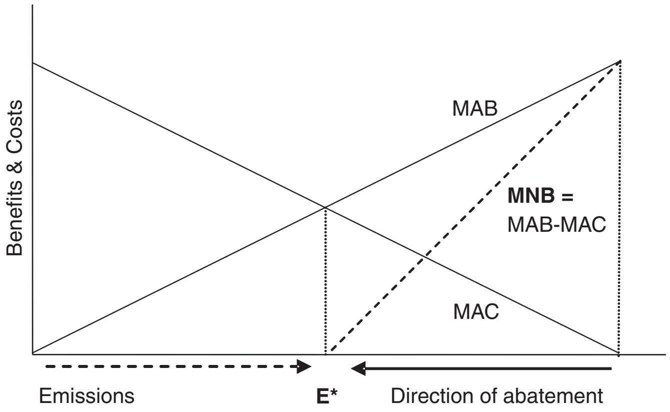

Fig. 1.

Both costs and benefits present measurement difficulties. Each emission reduction measure has its own costs, which in turn are likely to vary across firms, industries, households and locations.

On the benefits side, MAB are even more problematic. The impacts of pollutants range from damage suffered by engineering structures to increased health costs and lost labour productivity. Despite the existence of well-researched dose–response functions, the physical effects of pollution remain difficult to assess. Even more difficult is their reduction to financial terms, needed to calculate a pollutant's marginal damage function.

From a policy perspective, the notion of "optimal" emissions levels can have little relevance at a national level: such optima necessarily vary with location. Local factors like topography, population level and density, and prevailing wind direction, can influence both abatement costs and benefits. Consequently such optima are of little value when national or regional pollution standards are being determined.

Regulation, which sets uniform national standards for polluters, can impose unnecessarily high reduction costs. It is, however, often the most expedient measure; politically superior, quick to initiate and showing the authorities 'getting something done'. Visible official pollution controls can also offer benefits to polluters: these include efficiency related savings and access to markets where high environmental standards are required. On the other hand, measures that do not use legal coercion (such as self-regulation by industry, electrification of cities and encouraging insulation of houses) might achieve the same emissions reduction benefits while saving the administrative costs of regulation.

The new South African Clean Air legislation addresses some of these problems by using three levels of implementation. The weakest standards are national, and apply even in sparsely settled rural areas. The second level is set by provincial authorities who have the option to impose tighter regulations. Finally, at an individual city level, municipalities can opt for even more stringent standards.

While this makes the new act a more efficient system of regulation, it remains unclear that its implementation is the most cost-efficient way to address the air pollution problems faced by the public. The state has a variety of alternatives to coercive regulation: these include education, peer pressure, public disclosure programmes and economic instruments. The socio-economic impacts of a given level of abatement will naturally vary considerably with the tool (and timing) chosen.

At the heart of the pollution debate in environmental economics is a key proposition: emissions themselves are not the problem, it is the damage they do. A given emission in a city has very different consequences to the same emission in a rural area. There are a variety of reasons for this: most obviously, the number of potential 'victims' is greater in a city. In addition the level of ambient pollution is likely to be higher in urban areas—a problem if damage is an increasing function of pollutant concentrations—and the environment's ability to assimilate pollutants may be weaker in a city than in a rural area.

The South African Clean Air Initiative ostensibly aims to find the most economically efficient means of reducing air pollution. It should be clear that its true aim must be to reduce the impacts of air pollution efficiently. It is for this reason that it focuses on major conurbations and identifies health impacts averted as the measure of benefits.

If the aim is to minimise the negative externalities associated with air pollution efficiently, two broad response categories immediately present themselves.

Reduce emissions: this broad category includes all interventions that substitute a cleaner fuel (e.g. LPG for petrol), improve an existing fuel (e.g. change the oil distillation process to reduce sulphur levels in diesel), reduce emissions associated with an existing fuel (e.g. adding lime reduces SO_x emissions from coal fired power stations), or improve the efficiency of fuel use.

Reduce impacts: the classic methods are:

(a) to relocate the emission source *directly* (e.g. relocating a factory to a new site away from urban areas);
(b) relocate the emission *indirectly*; the most obvious example is electrification of high density townships. Since the bulk of electricity is from coal-fired generators, one is replacing inefficient combustion of coal in urban households that have low chimneys, with combustion of the same coal in more efficient furnaces, with higher stacks, and often in rural areas;
(c) relocate the 'victim' population or at least ensure that they are fully aware of the consequences of moving into the problem area;
(d) engage in defensive expenditures.

2.1. Proposed interventions

The research reported in this paper followed the intent of the Clean Air Initiative by addressing air pollution in major conurbations and focussing on health benefits in the form of reductions in morbidity and mortality. These were obtained using dose–response functions, and translated into economic terms by looking at their implications for medical costs saved, additions to days at work, and increased labour productivity.

Thirty-two different interventions were initially presented for assessment (see Appendix A). Of these, six could not be analysed because of incomplete or unreliable financial information or because the scope of the intervention was poorly defined. These interventions (12, 16, 17, 19, 24 and 28) were dropped before the economic analysis was initiated, though the engineering feasibility and dose response measurements were already available for some of them. The study could not go further because the terms of reference specified only these interventions. Hence the analysis of reduced electricity demand, for example, could not be done because we did not have the information on the degree to which this would reduce emissions.

The study generated a policy-relevant decision function by ranking measures in order of their benefit/cost ratios. This ensures that overall marginal net abatement benefit starts at the highest possible level, falling as the more efficient options (i.e. those with significant benefits at lower costs) are exhausted and marginal costs move closer to marginal benefits. When the benefit/cost ratio falls to one, the optimal mix of intervention has been identified and no further interventions are economically efficient.

The interventions analysed in the study have been sorted into the six categories listed below.

- use the same fuel more efficiently, e.g. top down ignition of coal;
- home insulation to reduce fuel demand;
- process the same fuel differently, e.g. low smoke coal or low sulphur diesel;
- use the same fuel differently, e.g. adding lime to coal-fired power stations;
- use the same fuel in a different place, e.g. electrify, shifting combustion of coal from households to distant power stations;
- use a different fuel, e.g. power cars with LPG rather than petrol.

The interventions are detailed in Appendix A, and their net present values (NPVs) and benefit–cost ratios are summarised in Table 2.

2.2. Method

In the Nedlac debate on the management of air pollution, the sectoral impacts of the emissions reductions were an obvious concern. The costs and benefits of any emissions abatement strategy will not be spread evenly across the economy. Estimating them presents both technical and economic challenges.

This study used financial and economic cost benefit analyses extended by employment impact studies. The data used was partly primary, sourced in parallel engineering/health studies commissioned by Nedlac, and partly taken from the available literature. It must be stressed that the focus of the study was the health care costs of air pollution in urban areas and it was not able to take into account the wider costs of air pollution and the associated benefits of its reduction.

The difference between the financial and economic results is that the financial analysis looks at monetary costs and benefits of the alternatives while the economic analysis looks at the costs to society. This latter analysis is done by adjusting for shadow prices and wages and removing the distortions caused by taxes and subsidies.

In this evaluation, transfer payments are netted out, and market prices are adjusted through the use of shadow prices reflecting scarcity and opportunity costs of goods consumed. Financial costs and benefits were converted to economic costs and benefits by allowing for VAT, company taxes, shadow pricing and subsidies. In so doing, the actual cost to society was determined. The shadow prices used in the analysis were sourced from Conningarth, 2002. These are:

- Shadow wages were used for unskilled labour (pay-classes were specified). All other pay-classes were used at current salary scales.
- Shadow fuel price for petrol and diesel.
- A shadow electricity price.
- A shadow exchange rate and import duties for those components that would be imported.
- Real discount rate: a real discount rate of 10% was used, as specified by the National Treasury.
- Direct and indirect taxes and subsidies were incorporated into the CBA model.

The analysis had two segments. The first assessed each individual measure in isolation; the second considered the combined impacts of the measures. The study estimated costs and benefits before and after correction for market distortions and indirect economic impacts. The sectoral effects of these impacts for the major stakeholders, government, firms and households, were also identified.

The interventions were all subjected to the same analysis. The outcome was a standardised set of results covering annual costs and benefits, NPV and benefit-cost ratios from both simple financial and broader economic perspectives, NPVs of impacts by affected sector, and inter-temporal employment implications by sector.

All of the pollution reduction measures described would improve public health, decreasing the short run demand for healthcare services. However, since the public healthcare service is severely over-burdened, such a decrease seems unlikely to engender job losses or budget cuts; the resources saved will merely be shifted to address the country's other health problems. Private healthcare could, however, be affected by this decrease in demand. Only the impacts on private healthcare revenue and employment were therefore included as "impacts on healthcare" in the extended analysis.

The polluting abatement interventions were ranked in order of their benefit/cost ratios. This ranking generated a de facto pollution abatement MNB function by representing the costs of the next cheapest reduction measure. Some of the interventions were mutually exclusive while others logically followed one another. To address this problem, appropriate combinations of measures were also modelled together.

Valuing decreased mortality rates presented a major methodological challenge. Strictly, the benefits of decreased mortality should be assessed using the value of a statistical life (VSL), itself derived using revealed preferences: i.e. individual's own valuations of risks to their lives. Freeman clarifies this as follows:

> … the economic question being asked is not about how much an individual would be willing to pay to avoid his or her death or how much compensation that individual would require to accept that death. In this respect, the term "value of life" is an unfortunate phrase that does not reflect the true nature of the question at hand. Most people would be willing to pay their total wealth to avoid certain death; and there is probably no finite sum of money that could compensate an individual for the sure loss of life. *Rather, the economic question is about how much the individual would be willing to pay to achieve a small reduction in the probability of death during a given period [own italics]* or how much compensation that individual would require to accept a small increase in that probability. [Freeman, 1993, p. 320].

Once a VSL estimate has been generated it can be multiplied by decreased mortality numbers (generated using dose–response functions) in order to arrive at an estimate for mortality benefits from decreased pollution. The dose–response functions were provided by other specialist studies which were commissioned alongside this economic study. Certainly the valuation of mortality reduction benefits remains difficult and controversial. Unfortunately such valuations were central to this study since mortality reduction often generated a large portion of total pollution reduction benefits. The analysis used three values for a statistical life. The upper value was given by the willingness to pay (WTP) estimates transferred from other studies. The lower value used a local human capital approach to VSL, while the average of these two provided an intermediate value. The robustness of the analysis to these upper and lower values was tested in a sensitivity analysis—see Section 3.3.

A number of techniques have been proposed for estimating WTP for reduced mortality risks, or willingness to accept (WTA) increased risk of death. Pearce and Howarth (2000) convincingly argue that estimates based on properly constructed contingent valuation surveys are the most likely to produce worthwhile results. Unfortunately, contingent valuations of this sort are time consuming and expensive. Practical constraints meant that this study was restricted to a benefits transfer approach, adapting values obtained by researchers elsewhere.

When assessing the benefits of the United States' Clean Air Act (EPA, 1999a), analysts had conducted a meta-analysis of 26 VSL estimates found in the literature. The majority clustered between US$3 million and US$7 million, with a central estimate of US$5 million in 1990 terms (EPA, 1999b). However, most of these estimates were generated by wage risk models, and some were controversially high (the highest was US$13 million). Only five studies among the 26 used contingent valuation. The average VSL among these was a seemingly more realistic US$2.88 million. In order to ensure a conservative approach, this estimate was reduced to US$1.44 million in line with Krupnick et al.'s (2000, p. 40) later estimates that were one half (or less) the size of the figures used by the EPA. This value was then converted to 2003 rands.

Following standard practice outlined in Pearce and Howarth (2000), these values were adjusted for differences in income levels between the USA and South Africa as follows:

$$B_{\mathrm{SA}} = B_{\mathrm{USA}}\left(\frac{Y_{\mathrm{SA}}}{Y_{\mathrm{USA}}}\right)^{\eta_y},$$

where B_{SA} is the benefit value in South Africa, B_{USA} the benefit value from the United States, Y_{SA} is the average income level in South Africa, Y_{USA} the income level in the United States and η_y the income elasticity of demand for factors affecting statistical life. Clearly the income elasticity chosen can crucially affect the outcome of the transfer. There are a few points worth emphasising. Firstly, if income elasticity of demand for such goods is zero, WTP and WTA should theoretically be identical as there is no income effect. Secondly, if the *proportion* of expenditure dedicated to such goods and services increases with income, the income elasticity will be higher in affluent areas than in poor areas. While the income elasticity of demand for health-related goods and services is not known in South Africa, it seems likely, a priori, that their demand is normal. Pearce and Howarth cite a set of observations of income elasticities between 0.3 and 1.1, for such goods that could reduce risk to life. Most of the observations were in the region of 0.3 (Pearce and Howarth, p. 33). Nonetheless, in order to ensure conservative benefit estimates we have assumed an income elasticity of 1.5. The reason for doing this is that it can be argued that low income countries are likely to have a considerably higher elasticity for health services than richer developed countries where there are already widely available public and private health services.

A potential problem is that the resulting estimate describes a single 'statistical' life. It therefore runs the risk of being an under (or over) estimate if applied uniformly to a particular age cohort. Various techniques are available to address this effect. One of the simpler and potentially less biased approaches is to apply a single age adjustment based on whether or not an individual is likely to be over 70 at time of death (EPA, 2002a). This is consistent with observations by Jones-Lee (1989), and Jones-Lee et al. (1993) and more recent findings by Krupnick et al. (2000) that the only significant difference in WTP is between those under and those over 70. To correct for this effect an adjustment factor is applied to those over 70. This factor (the ratio of a 70 year old individual's WTP to the WTP of a 40 year old) has been estimated at 0.63 (Jones-Lee, 1989) and 0.92 (Jones-Lee et al., 1993). To maximise the impact of the age adjustment, this study used the lower of these estimates.

As mentioned earlier, the approach described above provided the upper bound for the value of mortality reduction flowing from improved air quality. A human capital-based valuation provided the lower bound. This approach captures the opportunity costs of labour and is therefore closer in spirit to the shadow pricing method suggested for cost–benefit analysis. It also introduces income as an issue directly rather than via the mean income differentials used in benefits transfer. Human capital losses were quantified by simply multiplying work days lost through illness or premature death by the average incomes of those affected. For both the human capital based and the VSL approaches data on working days lost through illness and the number of premature deaths was taken from other specialist studies. This research (also commissioned by NEDLAC) used accepted dose–response functions in order to predict what health responses (i.e. number of work days lost through illness and number of premature deaths) would result from given doses of pollution. These estimates were then converted into economic values for VSL and human capital losses using the methods described above.

2.3. *Identifying and valuing the benefits*

A variety of benefits were identified and valued during the course of the study. Some of the benefits were common to all interventions while others were specific to a particular intervention. The three benefits common to all interventions were reduced health care costs, increased productivity and reduced mortality. The intervention-specific benefits included reductions in demand for coal, wood (for burning), electricity, etc. Also included were savings in stove maintenance, savings in lime, savings in capital and operating expenditure for electricity generation, anti-knock savings (for lead free fuels) and fuel savings (when substituting LP gas for other fuels).

In some cases the benefits of the interventions were determined by actual small-scale experiments conducted. As an example, for the Basa Mjengo Ngogo intervention, laboratory tests indicated the reduction in coal usage per household by using the new lighting technique. These results were verified by an experimental roll-out in a township, and the results then extrapolated to account for the larger townships.

In other cases, a social accounting matrix (SAM) for South Africa was used to determine the impact on role players. For instance, the SAM was used to determine the proportion of turnover that is paid as taxes for the coal industry as a whole. By quantifying the reduction in demand for coal, it was thus possible to determine the reduction in taxes that would be paid to the government. To counter this, the government would save in their subsidies to the coal sector. The net effect of the drop in taxes received and subsidies paid by the government is then attributed.

Estimates for productivity gains and reduced health care costs were made in the following manner. Each intervention improves air quality and reduces the number of patients hospitalised by relevant medical conditions. Estimates of these hospitalisation reductions were provided to this study by other specialist studies and the methodologies for these are not reported here. These estimates were multiplied by the average number of days spent in hospital for each condition to determine the reduction in the total number of hospital days, as determined from hospital records. The result was then augmented by the number of days in-patients spent at home recuperating. Statistics of historic ratios of in-patients to out-patients enabled calculation of the reduction in the number of out-patients due to each intervention. Reduction in total days off work taken by out-patients was estimated using historic data on the number of days that out-patients took off work beyond the time spent visiting the hospital.

Impacts of emissions reduction on members of the public suffering from relevant medical conditions, but not attending hospitals as either in- or out-patients, were also addressed. This was done using a ratio of in- and out-patients to non-patients, combined with industry estimates of days lost by such non-patients.

The total reduction in days off work for each intervention was calculated by summing the number of days off work for each of the in-patients, the out-patients and non-patients. For each conurbation we were able to determine the unemployment rates, the average incomes and the proportion of the economically active population employed in the private sector [as opposed to the public sector]. The impacts of emissions reductions on days lost were corrected accordingly; being applied to the economically active proportion (i.e. excluding children, the aged and unemployed) of those people taking time off work to determine the increase in productivity.

3. Results

To illustrate the approach taken we begin with an example of one of the more promising interventions.

3.1. Analysis of intervention no 1: top down ignition

This intervention would educate the public to practice efficient fuel stacking and top-down ignition when lighting coal stoves (the more common practice is to ignite the coal from the bottom). The result is twofold: a cleaner and less polluting start to the fire, and a reduction in actual coal used. Locally this project is called *Basa Njengo Magogo* (lighting a fire like a Grandmother). It is being initiated in Johannesburg and the Mpumalanga Highveld, the areas of the country with the greatest numbers of households using coal for cooking and heating.

The financial and economic cost–benefit analysis is given in Table 1. Here the NPV is given in 2003 prices (the base year for the study) as well as the costs and benefits for a selection of years. The costs and roll-out details had not been fully articulated when research began. There was an approximate overall cost with no indication of its

Table 1
Financial and economic cost benefit of intervention 1

		2003 NPV	2004 1	2010 7	2011 8	2012 9	2013 10
Financial CBA	*Financial CBA*						
	Implementation cost	−3,613,839	−628,861	−628,861	−628,861	0	0
	Coal savings	94,059,505	0	0	20,395,500	20,395,500	20,395,500
	Healthcare savings	511,462,151	0	0	110,903,479	110,903,479	110,903,479
	Electricity savings	0	0	0	0	0	0
	Other costs / savings	0	0	0	0	0	0
	Increased productivity	106,388,755	0	0	23,068,927	23,068,927	23,068,927
	Reduced Mortality	47,977,776	0	0	10,398,679	10,399,593	10,400,514
	Total Costs	−3,613,839	−628,861	−628,861	−628,861	0	0
	Total Benefits	759,888,187	0	0	164,766,585	164,767,499	164,768,420
	Difference	**756,274,349**	**−628,861**	**−628,861**	**164,137,724**	**164,767,499**	**164,768,420**
Economic CBA	*Economic CBA*						
	Implementation cost	−3,714,575	−646,391	−646,391	−646,391	0	0
	Coal savings	78,657,632	0	0	16,882,154	16,915,246	16,949,708
	Healthcare savings	424,402,248	0	0	91,721,814	91,782,298	91,844,403
	Electricity savings	0	0	0	0	0	0
	Other costs / savings	0	0	0	0	0	0
	Increased productivity	106,388,755	0	0	23,068,927	23,068,927	23,068,927
	Reduced Mortality	47,977,776	0	0	10,398,679	10,399,593	10,400,514
	Total Costs	−3,714,575	−646,391	−646,391	−646,391	0	0
	Total Benefits	657,426,412	0	0	142,071,574	142,166,064	142,263,552
	Difference	**653,711,836**	**−646,391**	**−646,391**	**141,425,183**	**142,166,064**	**142,263,552**

US \$1 = approx. R7

disposition over time. The roll-out had been planned for 2007. Due to this lack of detailed information a conservative approach was followed. To account for planning and facilitation costs prior to the start of the education process, the costs were spread evenly between 2004 and 2011. In keeping with the conservative approach potential early benefits were not incorporated (and were not available), hence benefits were included from 2011 onwards. From a financial perspective the present value of the cost of the intervention was R3.6 millions(m). The present value of the benefits was R94 m in coal saving, R511 m in healthcare saving, R106 m in increased productivity and R47 m in reduced mortality. The overall financial costs had a present value of R759 m and the entire intervention had a financial NPV of R756 m.

The financial costs and benefits were then converted into economic equivalents by adjusting for missing markets, VAT, tariffs/quotas, indirect taxes and subsidies, exchange rate and factor market distortions. Shadow price adjustments were performed for unskilled labour; petrol and diesel; electricity and exchange rates where relevant, using shadow prices provided in the current South African CBA guideline document (Mullins et al., 2002). After making these adjustments the present value of the economic cost was R3.7 m, the present value of the economic benefit was R657 m and the overall NPV was R653 m.

These estimates and their changes over time, as well as costs and benefits to stakeholders, are illustrated in Fig. 2. The stakeholder analysis indicates that the financial benefits of *Basa Magogo* to government and households have present values of R414 m and R173 m respectively, while firms would incur net costs with a PV of R76 m. Focusing on the economic impacts on firms, demand affected firms (i.e. those selling coal) absorb most of the first round costs (PV of R150 m which reflects the R76 m above before correction for increased labour productivity benefits generated by a healthier workforce). It is uncertain whether the change in coal demand will generate a change in coal price: a priori household demand for coal is likely to be price inelastic downwards and yet more elastic for price rises (due to the number of substitutes that become viable as the coal price rises). The four largest coal producers, as well as Eskom (the national electricity generator), would also incur costs (economic PV R2.8 m) as they would be expected to contribute funds to the project. Productivity benefits were estimated for firms employing workers whose health would be improved by the measure. These had a PV of R106 m.

Households would save through reduced purchases of coal—PV of saving being approximately R150 m. Total wage benefits accruing to household members who are employees of the programme would have a PV of R1.8 m. Households that contain healthcare employees would incur a cost with a PV of R59 m as demand for these services dropped. Mortality reduction benefits with a PV of R48 m would also accrue to households.

Impacts on employment were a concern. The project would generate 2–3 (average annual) new jobs as project educators against a loss of 44 jobs per annum in the private health care sector. There would be no job losses in the mining sector since there is an existing (unsatisfied) excess demand for coal on the part of local industries. The apparent low number of jobs for educators is because these are annual average jobs spread over a 20 year period, although the educators would only be employed in the early years. Job losses would in all likelihood also occur among coal merchants as the volume of sales decreased, although this impact could not be quantified due to lack of data.

3.2. Overall assessment of interventions

Each intervention was analysed in the same way as intervention 1 above. The NPV and benefit–cost ratio of each intervention are reported in Table 2.

Interventions 1, 2, 4, 5, 6, 7, 8, 9 10, 12, 26, 27, 29 and 32 had positive NPVs. Interventions 3, 11, 13, 14, 18, 20, 21, 22, 23, 25, 30 and 31 had negative NPVs.

Intervention 7 has the highest positive economic NPV followed by interventions 10, 32, 2 and 29. Intervention 11 has the highest negative economic NPV followed by 14, 13, 3 and 18. One issue emerges immediately: the bulk of interventions with positive NPVs are household based, while those with negative NPVs are industry based. The conclusion that one draws from this is that cost–effective treatment of reducing the health care costs of the air pollution problem in South Africa's cities should begin by addressing household rather than industrial sources.

The reason for these unexpected results is that legislation on industrial emissions has been in place and well monitored for many years, and petrol/diesel quality is already reasonable; in consequence all the "low hanging fruit" on the industrial and vehicular sides are already gone. Whatever benefits there are available from tighter standards can only be obtained at high cost. On the other hand low-income households have been subjected to virtually no regulation over the years and there is considerable opportunity to improve air quality in an economically efficient manner.

Theoretically, the optimal level of intervention per emission is attained when the marginal benefits provided by the emission (or the use of the dirty fuel) just match the marginal abatement cost of the intervention being used to reduce it. The mere reduction of a specific emission is not the ultimate goal of these interventions. Their aim is to cost effectively reduce health costs borne by the South African public. To show how this could be done, a variant on the common neoclassical approach was used. Technically feasible interventions were ranked by their benefit/cost ratios, establishing which were clearly and robustly justifiable. Of these, some offered large and immediate benefits, others smaller ones. From a policy perspective, one would like to see the larger, strongly positive, interventions pushed forward first.

Fig. 2. Analysis of Intervention 1—Top Down Ignition.

Four interventions were excluded from the marginal benefit–cost analysis. Because these interventions are already in the process of being introduced, their costs are akin to ‘‘sunk costs’’ and as such should be excluded from cost–benefit analyses. Each outcome therefore shows the present value of the benefits associated with it, and is reported for information purposes only. These are numbers 12, 26, 27 and 29. Intervention 12 is the decommissioning of an existing power station in a major urban area. The remaining three cover the

Table 2
NPVs and benefit-cost ratios of interventions

Net present values for all interventions		Net present values (Rm)		Economic BC ratio
Int		Financial	Economic	
1	Top down ignition—plateau roll out	756	654	177.0
2	Top down ignition—all conurbations	1,123	968	120.1
3	Low-smoke fuels	−3,592	−2,914	0.4
4	Housing insulation—5% of plateau fuel burning households	263	226	6.0
5	Housing insulation—20% of plateau fuel burning households	1,052	904	6.0
6	Housing insulation—5% of all fuel burning households	426	368	7.9
7	Housing insulation—20% of all fuel burning households	1,704	1,470	7.9
8	Electrification of households	1044	790	1.2
9	Stove maintenance and replacement—5% of all households	325	277	16.5
10	Stove maintenance and replacement—20% of all households	1,300	1,107	16.5
11	Desulphurisation of all power station emissions	−15,446	−12,769	0.0
12	Decommission of Pretoria West power station	159	138	20.8
13	Renewable wind energy (10,000 GWh block)	−5,429	−4,485	0.3
14	Renewable wind energy (37,000 GWh block)	−6,341	−5,211	0.3
15	Emission reductions for coal fired boilers	−191	−174	0.8
16	Iscor coke over gas cleaning project	0	0	
17	Highveld Steel and Vanadium replace coal with CO	0	0	
18	Desulphurisation of Sasol Secunda power station emissions	−1,934	−1,593	0.1
19	DME strategy to reduce sulphur content of petrol to 500 ppm	0	0	0.0
20	DME strategy to reduce sulphur content of petrol to 50 ppm	−1,116	−946	0.0
21	DME strategy to reduce benzene content of petrol to 1%	−1,094	−927	0.0
22	DME strategy to reduce aromatics content of petrol to 35%	−1,235	−1,051	0.1
23	DME strategy to phase out leaded petrol	0	0	1.0
24	DME strategy to reduce sulphur content of diesel to <500 ppm and second	0	0	0.0
25	DME strategy to reduce sulphur content of diesel to 50 ppm	−442	−365	0.5
26	DME strategy for all new vehicles to comply with Euro 2 standards	627	540	
27	DME strategy for all new vehicles to comply with Euro 4 standards	420	361	
28	Taxi Recapitalisation Programme	N/A	N/A	N/A
29	DME strategy for all petrol vehicles to be Euro 2 compliant	1,054	907	
30	Conversion of 10% of petrol vehicles to LPG	−2,383	−226	1.0
31	Conversion of 20% of petrol vehicles to LPG	−4,765	−451	1.0
32	Electrification of affin bur households	0	999	1.3

adoption of ‘Euro 2’ and ‘Euro 4’ technology standards on new vehicles.

If interventions are introduced in order of their benefit/cost ratios, the marginal intervention should be the one in place when the marginal benefit it provides just matches the marginal abatement cost incurred through its use. If the impacts and costs of the intra-marginal interventions are known, then the optimal policy interventions should be clear.

Fig. 3 contains two curves. The first is the marginal benefit/cost curve, which slopes from the top left hand corner down to the bottom right and represents the benefit–cost ratios of the interventions analysed. The second curve is the horizontal line corresponding to a benefit/cost ratio of 1. Only interventions above the line are economically justifiable in reducing the health care costs of air pollution. In effect there are ten air quality interventions that are likely to enhance net societal welfare, and these should be introduced in the order of their benefit cost ratios: i.e. 1, 2, 9, 10, 6, 7, 5, 4, 32 and 8. Effectively this picks up all interventions with positive NPVs, and ranks them in order of their economic efficiency.

3.3. *Sensitivity analysis*

The household interventions were tested for their sensitivity to assumptions regarding VSL, productivity and discount rate. They proved robust in respect of all three. Changes in the discount rate naturally affected NPVs, but did not change either the benefit–cost rankings of the interventions or the sign of NPVs. Similar results were found for both the VSL and productivity.

Five changes were made to the VSL as part of the sensitivity analysis: it was set to zero; based on WTP measures for very low income households; based on WTP measures for low income households; based on a human capital approach using an average annual income of R26 000 per person (NPV of earnings = R176 260); and, based on an average between WTP measures and average lifetime income stream. Sensitivity to estimated productivity benefits of improved air quality was done using three standards: (a) no productivity benefits (b) half productivity benefits and (c) double productivity benefits. In all cases the ranking based on benefit-cost ratios remained unchanged and the ratios remained above one.

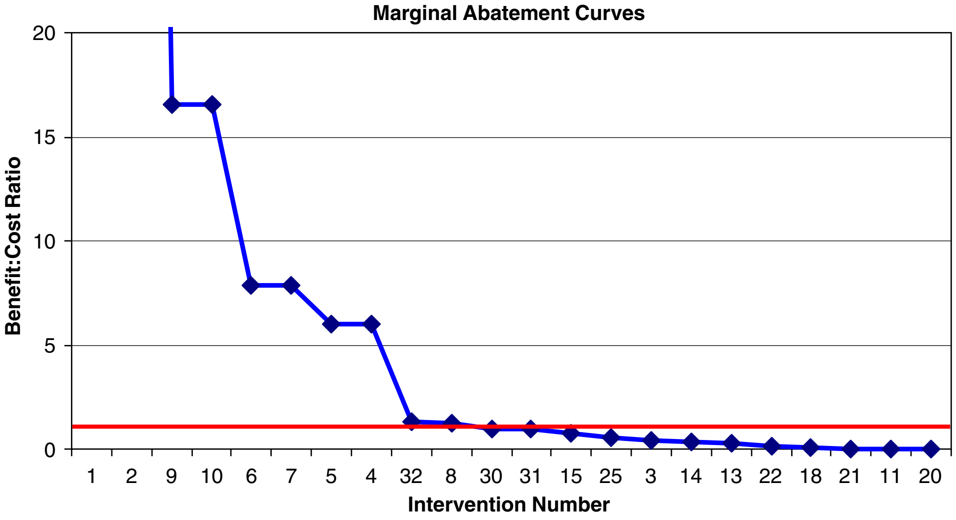

Fig. 3. Marginal net benefit ratios by intervention.

4. Conclusions

Any regulator hoping to reduce air pollution finds that there are many ways to reduce the socio-economic impacts of pollution. A uniform, 'one size fits all' centrally administered regulation, that sets a single acceptable target for any emission, cannot be economically efficient. Such determinants of optimal emissions as population density, topography and opportunity cost are likely to vary from one location to another.

The optimal level of intervention per emission is attained when the marginal abatement benefit provided by reducing the emission (or the use of the dirty fuel) just matches the marginal abatement cost of the intervention. It was found that the bulk of interventions with positive NPVs for reducing the health care costs of air pollution are household based, while those with negative NPVs are industry based. This suggests that cost effective treatment of the air pollution problem in South Africa's cities should begin by addressing household rather than industrial sources. More importantly, it provides economic justification for redistributional policies such as provision of subsidised electricity or LPG to the urban poor.

Appendix A

Eight of the interventions aimed at using the same fuel more efficiently:

- Intervention no 1: The Basa Njengo Magogo project, if implemented *only in Johannesburg and the Mpumalanga Highveld*. The project educates the public about the health and efficiency benefits of the efficient stacking and top-down ignition of coal stoves as opposed to more common practice of bottom up ignition.
- Intervention no 2: Basa Njengo Magogo project, extended to *all* South African cities.
- Intervention no 9: Coal stove maintenance and parts replacement for 5% of households in all urban areas.
- Intervention no 10: Coal stove maintenance and parts replacement for 20% of households in all urban areas.
- Intervention no 26: Department of Minerals and Energy (DME) strategy for *new* passenger vehicles to comply with Euro 2 standards.
- Intervention no 27: DME Strategy for *new* passenger vehicles to comply with Euro 4 standards.
- Intervention no 29: *All* petrol vehicles to be made Euro 2 compliant.
- Intervention no 23: DME Strategy for the phasing out of leaded motor vehicles fuels.

Four of the interventions investigated would reduce or negate the need for heating fuel. All of these involved improved housing insulation.

- Intervention no 4: Housing insulation for 5% of households heated by fuel burning *in Johannesburg and the Mpumalanga Highveld*.
- Intervention no 5 aimed at increasing this percentage to 20%.
- Intervention no 6 aimed at providing housing insulation for 5% of *all* the country's fuel burning urban households.
- Intervention no 7 would extend this to 20% of these households.

A number of interventions aimed at using the same fuel, but only after the fuel had been processed to reduce potential emissions. These are:

- Intervention no 3, the development of low smoke fuels. The programme would entail the production and distribution of coal treated to reduce the health impacts of its combustion.

- Interventions 19–25 (excluding 23) reduce the sulphur, benzene and aromatics content of petrol and diesel, respectively.

Four interventions aimed at using the same fuel in a different way.

- Intervention no 11 aimed at the desulphurisation of all power station emissions. The sulphur (SO_x) released when coal is burnt for power generation is a significant source of air pollution, particularly in Mpumalanga.
- Intervention no 15 would reduce particulates emitted from coal-fired boilers.
- Intervention no 16 aimed at reducing emissions from the Iscor coking ovens. Iscor is the largest steel refinery in the country.
- Intervention no 18, desulphurisation of Sasol Secunda power station emissions.

Three interventions were based on aspects of electrification. Since the bulk of South Africa's electricity is generated at coal-fired thermal power stations, the first two imply using the same fuel, but more efficiently and in a different place. These are:

- Intervention no 8 aimed at the electrification of households. Electrification would improve air pollution levels as consumers switched away from coal stoves and the use of other primary sources of fuel.
- Intervention no 12 is the decommissioning of an old power station to the West of Pretoria.
- Intervention no 32 aimed at the electrification of paraffin burning households.

Finally, five interventions aimed at substituting fuels.

- Interventions no 13 and 14 aimed at the implementation of wind-generated energy technology through financial incentives (10 000 and 37 000 GWh block, respectively).
- Intervention 17 was to replace coal with natural gas/carbon monoxide in an upgrade of Highveld Steel and Vanadium (a steel and stainless-steel smelter).
- Interventions no 30 and 31, respectively, aimed at converting 10% and 20% of petrol vehicles to LPG.

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