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Paradoxes of rationality in road safety policy

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ABSTRACT

Rationality is an ideal for transport safety policy. As developed within normative welfare economics, rationality denotes the efficient use of safety measures based on cost-benefit analyses that include all relevant impacts of the measures. Efficiency in the technical sense of the term provides a perfectly clear and precise guideline for policy priorities. Nevertheless, some choices that are guided by cost-benefit analysis may strike us as paradoxical or counterintuitive. A paradox of rationality refers to any situation in which conflicting choices can both be defended as rational. This paper discusses a number of choices that may seem paradoxical. The first involves the choice between options that have identical impacts on safety, but in which these impacts are valued differently. The second deals with the tendency for preference reversals to occur when preferences for the provision of safety are aggregated. The third discusses the inability of conventional measures of willingness-to-pay to reflect the intensity of preferences. The fourth concerns the tendency for policy choice to favour the rich at the expense of the poor when willingness-to-pay is not adjusted for the marginal utility of money. A fifth situation refers to the fact that a policy option that looks attractive ex ante may fail an ex post compensation test because utility functions depend on health state. There is a potential conflict between individual and collective rationality with respect to the costs and benefits of some road safety measures. When developing a road safety programme, a set of road safety measures whose benefits exceed the costs when considered as stand-alone measures could have benefits smaller than cost when combined in a programme consisting of all the measures. Finally, there is a potential conflict between efficiency and negotiated consensus as mechanisms of resource allocation in the public sector. The sources of the paradoxes and ways of avoiding them are discussed. Some of the paradoxes can be avoided if changes in risk are valued in terms of a fixed price per unit of risk rather than according to a non-linear demand function.

Key words: cost-benefit analysis, road safety policy, rationality, paradox, valuation

1 INTRODUCTION

“One kind of optimism, or supposed optimism, argues that if we think hard enough, are rational enough, we can solve all our problems” (Simon 1983, page 3). Rationality is a widely supported ideal of public policy; yet the implementation of this ideal to road safety in terms of a policy based on cost-benefit analysis remains controversial (Ackerman and Heinzerling 2004, Hauer 1994, 2011). There is evidence that actual policy priorities for safety are not always perfectly rational. Tengs et al. (1995) examined more than five hundred life-saving interventions and found that the cost per life-year saved varied enormously between these interventions. A subsequent analysis (Tengs and Graham 1996) found that efficient priorities, i.e. marginally spending the same amount per life-year saved in all interventions, had the potential of saving about 60,000 lives per year in the United States. Despite this, it is not obvious that efficient priority setting in safety policy can be easily implemented. To use cost-benefit analysis as a means of setting efficient priorities, one needs a monetary valuation of life-saving. The values currently found in the literature vary enormously (Hauer 2011, Lindhjem et al. 2011) and do not seem to reflect well-ordered preferences (Loomes 2006, Sugden 2005).

There is a large literature (for an overview, see e.g. Slovic 2000) showing that risks and changes in them are not always correctly perceived; risks that are wrongly perceived as large may get disproportionate attention in public policy and more may be spent on controlling them than on controlling larger risks that are perceived as minor. Moreover, the possibility that people do not value all lives equally cannot be ruled out (Johansson-Stenman and Martinsson 2008). Hence what looks like inefficient or even haphazard policy priorities could in principle reflect a complex preference structure that does not assign the same value to the reduction of all types of risk or to the saving of all lives.

One can even imagine that the huge differences between safety programmes with respect to the implied value of saving a life are entirely consistent with a well-behaved demand function. When the valuation of life implied by regulatory decisions is reviewed, it is typically found that the implicit value of life is high when the risk regulated is low. Conversely, the implicit value of life tends to be low when the risk is high (Viscusi 1996). As will be shown later in this paper, such a pattern could be consistent with individual demand for safety. The objective of this paper is to examine some implications of basing priorities for safety strictly on individual demand for it. It is not suggested that current safety policy is actually based on individual demand as interpreted in this paper, nor is it suggested that official guidelines for cost-benefit analysis call for providing safety strictly according to the demand for it (see, for example, HM Treasury 2005).

The next section develops a framework for analysis. Based on that framework, the subsequent sections of the paper present a number of hypothetical policy choices in which arguments can be given against basing the choice on cost-benefit analysis. These hypothetical choices are not intended as examples of real policy choices, but have been framed to highlight situations that may be felt as dilemmas. Some of the choices that are discussed can be interpreted as paradoxes of rationality, i.e. situations in which conflicting choices can both be defended as rational.

2 FRAMEWORK FOR ANALYSIS

Analysis relies on the assumption that individual preferences for the provision of safety can be represented by means of a demand function based on the size of the risk reduction. It has furthermore been assumed that utility increases as a function of income, but the marginal utility of income declines monotonically (i.e. throughout the entire range of income). Finally, it has been assumed that individual utility functions depend both on income and on health state. Health state (at a given level of income) can be represented as a continuous quality-of-life variable that takes on the value of 1 in perfect health and 0 in death. Health state refers not just to the presence or absence of disease, but to what extent an individual experiences life in general as good and joyful.

2.1 Willingness to pay for improved road safety

The assumptions made regarding individual demand for improved safety are based on the results of a meta-analysis reported by Lindhjem et al. (2011). They found that the value of a risk reduction which corresponds to reducing the expected number of fatalities by one (the value of a statistical life, VSL) could be modelled in terms of the following function:

$$\text{Ln(VSL)} = 7.451 - 0.761 \cdot \ln(\text{change in risk})$$

For a change in risk of 1 in 1,000,000 (0.000001) this becomes:

$$\text{Ln(VSL)} = 7.451 – 0.761 \cdot \ln(0.000001) = 7.451 – 0.761 \cdot (–13.8155) = 17.9646$$

By taking the exponential function of this, the estimated value of a statistical life becomes 63,376,490 US dollars (2005). Since VSL is obtained as the marginal rate of substitution between income and risk, mean willingness to pay for a risk reduction of 1 in 1,000,000 can be estimated as:

$$\text{WTP} = \text{VSL} \cdot \text{risk change} = 63{,}376{,}490 \cdot 0.000001 = 63.8.$$

The demand function is:

$$\text{WTP} = 63.376 \cdot X^{0.239}$$

In this function, X denotes the size of the change in risk, which is usually stated per 100,000 or per 1,000,000. Marginal willingness-to-pay is the first derivative of the demand function, which is:

$$\text{Marginal WTP} = 15.147 \cdot X^{–0.761}$$

The resulting values for WTP and VSL are shown in Table 1.

Table 1 about here

It is seen that willingness to pay increases as the size of the risk reduction increases but not in proportion to the size of the risk reduction. Marginal willingness to pay shows the additional amount paid per additional unit of risk reduction. The value of a statistical life is obtained by dividing willingness to pay by the risk reduction, for example 109.88/0.00001 = 10,988,241. It can be seen that while willingness to pay increases as a function of the size of the risk reduction, the value of a statistical life declines as a function of the size of the risk reduction. The function assumed for willingness to pay implies the demand function shown in Figure 1.The shape of the demand function which has been assumed resembles the typical shape of almost any demand function.

Figure 1 about here

2.2 Utility as a function of income and health state

As far as the utility of income and health state is concerned, the utility functions proposed by Kornhauser (2001) will be used as the starting point for analysis. For perfect health, Kornhauser proposed the following utility function with respect to income:

$\text{Utility} = 5 + 5 \cdot \ln(w + 1)$

The letter w denotes income, and ln is the natural logarithm. For death, Kornhauser assumed the following utility function:

$\text{Utility} = \ln(w + 1)$

It was stated earlier that the utility of health (on the 0 to 1 quality of life scale) equals 0 when a person is dead. It is, however, still conceivable that a positive utility of income exists, as a result, for example of bequest motives.

Utility in a state of reduced health can be represented by varying the constants, for example:

$\text{Utility} = 3 + 4 \cdot \ln(w + 1)$

This function yields a utility level of approximately 78 % of the utility of income in perfect health.

The three utility functions listed above are illustrated in Figure 2.

Figure 2 about here

The functions may seem to be very flat. However, the utility function for perfect health closely resembles a function that can be fitted to US data describing the relationship between income and points scored for happiness (Frey and Stutzer 2002) and may therefore be regarded as quite reasonable. The interpretation of happiness scores as an indicator of utility is discussed by Di Tella and MacCulloch (2006).

3 THE CHOICE BETWEEN OPTIONS WITH IDENTICAL IMPACTS ON SAFETY

Consider the choice between option A and option B in Table 2. In both options an initial risk of 20 per million is reduced. In both cases the risk reduction results in an expected reduction of 20 fatalities. Thus, the options are identical with respect both to initial risk and the number of fatalities prevented and no basis for preferring one option to the other exists in terms of these characteristics.

Table 2 about here

If choice between these options is to be based on monetary benefit, option A will be chosen. The monetary benefit of saving 20 lives in option A is more than three times greater than in option B. The reason for this is that the non-linearity of willingness to pay for safety with respect to the size of the risk reduction means that the value of a statistical life in option B is lower than in option A.

This result was discovered long ago. The first one to point it out was John Broome (1978), who argued that preferring one option to another when both options saved the same number of lives was a violation of the axiom of independence of irrelevant alternatives, which is one of the axioms of rational choice proposed by Von Neumann and Morgenstern.

It seems clear that Broome is right about this. One can imagine any number of combinations of background characteristics like initial risk, the size of the risk reduction, the size of the population benefitting from the risk reduction, the mean income of that population, the shape of the demand function, etc, etc, that would result in options that are:

1. Identical with respect to the safety benefits stated in natural units (lives saved, injuries prevented), and
2. Different in terms of the monetary valuation of the safety benefits.

If faced by a string of such choices, a decision maker adopting monetary benefits as the only criterion would in effect make the choice dependent on arbitrary factors influencing willingness-to-pay. It is fair to label these factors as arbitrary, since they are not subject to control by the decision maker and may vary randomly from one choice to another.

In responding to Broome, Jones-Lee (1989, page 20) states that: "... It is clear that under certain circumstances the dictates of coherence and consistency in government decision making will inevitably conflict with considerations of democracy (widely construed to include a requirement that government decisions should take account of individual wishes and attitudes to risk). In such conflicts, Broome appears to favour coherence whereas for advocates of the willingness-to-pay approach democracy is of primary importance."

This reply, although reasonable, does not really refute the argument made by Broome. Indeed, consistency in priority setting has been one of the main arguments economists have put forward to justify why a monetary valuation of life and limb is needed. It is therefore ironic when monetary valuations that are based on individual preferences do not ensure consistency in public policy based on these valuations.

4 PREFERENCE REVERSALS ASSOCIATED WITH PREFERENCE AGGREGATION

In Table 1, the column labelled willingness to pay shows individual preferences with respect to the provision of risk reductions of differing magnitudes. As can be seen, the largest risk reduction is the most preferred, the smallest risk reduction is the least preferred. These preferences are aggregated to form the value of a statistical life. As can be seen from Table 1, the value of a statistical life is highest for the smallest risk reduction, lowest for the largest risk reduction – exactly the opposite pattern of that found for individual willingness to pay. This may generate highly counterintuitive choices between options that involve a different number of lives saved. An example of such a choice is given in Table 3.

Table 3 about here

Initial risk is identical in the two options, but option B reduces risk much more than option A. Option B saves 2.4 times as many lives as option A. Nevertheless, if monetary benefit is used as the criterion of choice, option A will be chosen. This is problematic for several reasons:

1. Option B reduces risk by 12 in 1 million, whereas option A only reduces risk by 1 in 1 million.
2. Option B results in a final level of risk (8 in 1 million) which is lower than that attained by option A (19 in 1 million).
3. Option B saves 2.4 times as many lives as option A (24 versus 10).
4. Willingness to pay for option B is almost twice as high (114.78 versus 63.38) as willingness to pay for option A.
5. Preferring option A to option B can, all else equal, be considered as wasting money, since more lives could be saved by preferring option B.

This example goes straight to the core of the argument made by economists for basing priorities for safety measures on cost-benefit analyses, rather than setting priorities informally. It has been argued (see, for example Hills and Jones-Lee 1983) that setting priorities informally entails the risk of using public funds inefficiently, thereby saving fewer lives than if priorities were set according to an economic criterion ensuring consistency. The choice of option A in the above example – which on the surface might appear suboptimal if one assumes that the two options cost the same – is however perfectly consistent with the monetary valuation of the lives saved. The problem is that this valuation is not the same for the two options. In general, one would not expect the monetary valuation of lives saved to be invariant with respect to background characteristics. In practice a common value of life which is invariant with respect to background characteristics is normally used. In that case, option B would be preferred.

5 INABILITY OF CONVENTIONAL WILLINGNESS TO PAY TO REFLECT THE INTENSITY OF PREFERENCES

Hokstad and Vatn (2008), in discussing ethical dilemmas in road safety policy, introduce the notion of “relative willingness to pay”, which is intended to reflect the intensity of preferences for the provision of a good. They show, by means of a numerical example that a policy choice based on conventional willingness to pay may differ from a policy choice based on relative willingness to pay. The options and their estimated benefits in terms of conventional and relative willingness to pay are shown in Table 4.

There are 100 rich individuals and 900 poor individuals. Each rich individual earns ten times as much as each poor individual (500 versus 50). The rich individuals are willing to pay 5 for option A and 15 for option B. This amounts to 1 % and 3 %, respectively, of their income.

Table 4 about here

The poor are willing to pay 2 for option A and 1 for option B, amounting to 4 % and 2 % of their income, respectively. According to conventional willingness to pay, aggregate willingness to pay is 2300 [(100 · 5) + (900 · 2)] for option A and 2400 for option B. Thus, option B would be chosen. According to relative willingness to pay, on the other hand, option A [(100 · 0.01) + (900 · 0.04)] would be preferred (aggregate relative willingness to pay = 37 for option A versus 21 for option B).

This problem is very closely related to the failure of conventional cost-benefit analysis to account for differences between the rich and the poor in the marginal utility of money. If the utility function for perfect health proposed by Kornhauser (2001) is applied, the utility of income for the rich becomes:

Utility of income = $5 + 5 \cdot \ln(500 + 1) = 36.08$.

For the poor, the utility of their income is 24.66. Thus, although the rich earn ten times as much as the poor, their utility of income is only about 45 % higher than for the poor. The mean utility provided by each monetary unit of income for the rich is 36.08/500 = 0.072, whereas for the poor the corresponding value is 24.66/50 = 0.493. These indices can be used as "utility weights" in estimating willingness to pay adjusted for the marginal utility of money. Utility-adjusted willingness to pay becomes:

$(500 \cdot 0.072) + (1800 \cdot 0.493) = 923.81$ for option A and 552.11 for option B.

Whenever the groups that benefit from a measure differ greatly with respect to income, adjusting for differences in the marginal utility of money will make the groups more comparable in terms of the true costs and benefits to them of the options that are compared.

6 FAILURE TO ADJUST FOR THE MARGINAL UTILITY OF MONEY

Jones, Lyons, John and Palmer (2005) compared injury rates in child pedestrians in two towns before and after traffic calming measures were introduced. The population of each town was divided into quartiles based on the socio-economic status of the residential area. Table 5 shows the number of child pedestrians (aged 4-16) who were injured per 1,000 children before and after traffic calming in the highest and lowest quartiles by socio-economic status of the residential areas in the two towns.

Table 5 about here

Nearly all traffic calming measures were implemented in the most deprived areas of both towns. In town A, this policy greatly reduced the difference in risk faced by rich children and poor children when walking in their neighbourhood. A similar pattern, although clearly weaker, was seen in town B.

Willingness to pay for these changes in the risk of injury was estimated by assuming that mean income among the rich was 800,000 and mean income among the poor was 200,000. The utility functions of Kornhauser (2001) were applied, with:

$U = 5 + 5 \cdot \ln(w + 1)$ representing no injury; and

$U = 3 + 5 \cdot \ln(w + 1)$ representing injury.

Initial risk for the rich in town A was 2.97 in 1,000; final risk was 2.86 in 1,000. The levels of initial and final risk were analogously defined for the other groups.

Mean willingness to pay for the risk reduction was found by solving the following equation for m:

$$(1 - p)U(1,w) + pU(0,w) = (1 - p + r)U(1,w - m) + (p - r)U(0,w - m)$$

In this equation, p is the initial risk of injury, r is the risk reduction (the difference in risk from before to after), w is income, m is willingness to pay and U is utility. 1 denotes utility conditional on no injury, 0 denotes utility conditional on injury.

It turned out that in town A the policy of favouring the poor areas was confirmed by estimates of willingness to pay. The poor were, on the average, willing to pay considerably more for the safety improvements realised in their area, than the rich were for the rather modest improvement of safety in their area. In town B, however, the pattern was reversed. The rich in town B were, on the average, willing to pay more for a risk reduction in their part of town than the poor were willing to pay for a much greater risk reduction in their part of town.

If the budget for traffic calming had been determined according to willingness to pay, traffic calming in town B would have been carried out in the rich area. However, this conclusion is, as in the problem discussed above, based on “crude” willingness to pay, not adjusted for differences in the marginal utility of money. The addition of 2000 (= 1 %) to the annual income among the poor adds 0.05

units to utility (assessed in perfect health). An identical addition to the annual income of the rich adds only 0.012 units of utility. This suggests that the utility weight of expending a given amount of money among the poor is about 4 times higher than among the rich. If willingness to pay is adjusted by this weight, it becomes about 7175 among the poor in town B, considerably larger than willingness to pay among the rich (1900). Thus, a policy favouring the poor can be justified as efficient, provided willingness to pay is weighted according to the marginal utility of money. If such weights are not used, policy may favour the rich.

7 DIVERGENCE BETWEEN COMPENSATION EX ANTE AND COMPENSATION EX POST

The problem to be discussed in this section was first pointed out by Ulph (1982). It arises when utility depends both on income and health state, and the utility function is more risk averse with respect to health state than with respect to income. A project that passes an ex ante cost-benefit test may then fail an ex post compensation test. This means that benefits may be regarded as greater than costs before the project is implemented, but smaller than costs after the project has been implemented. This possibility is most relevant in cases where projects involving an increase in injury risk are considered. Such projects may not typically be part of a road safety programme, but in some cases the effects of road safety measures vary according to injury severity. An example is the construction of 2 + 1 roads in Sweden. These are three lane roads where a wire guard rail has been installed in order to prevent, or reduce the severity of head-on collisions. It has been found that the conversion of an undivided two-lane road to a 2 + 1 road with guardrail reduces the number of fatalities by 76 % and the number of serious injuries by 47 %. The number of slight injuries, however, increases by 13 % (Carlsson 2009).

Another regulation that might lead to an overall increase in risk is the withdrawal of the driving licence from older drivers. Driving a car tends to be the safest mode of travel for older road users. When driving ceases and is replaced by walking, cycling or the use of public transport, the risk of injury may increase. It is therefore of some interest to discuss the problem identified by Ulph.

A complication when discussing utility before and after a change in health status, is the fact that there is considerable hedonic adaptation among accident victims. This means that victims of even grievous injury, such as spinal cord injury leading to confinement to a wheelchair, will report almost the same level of happiness and general satisfaction with life after a period of adjustment as they did before they were injured. An early study showing this was reported by Brickman, Coates and Janoff-Bulman (1978). They compared self-reported happiness among lottery winners, paraplegic accident victims and a control group from the normal population. The lottery winners are of no interest in the present context, but key findings for the other two groups are reported in Figure 3.

Figure 3 about here

The reported levels of happiness have been converted to a scale in which the maximum value is 1.00. It can be seen that the accident victims reported a significant drop in their happiness just after the accident, but that they expect happiness to recover to almost the level before the accident. Similar findings have been reported by Nord (1999).

Suppose a measure that will increase the risk of a serious injury from 6 in 1,000 to 10 in 1,000 is considered. The ex ante question is how much compensation is needed to accept this increase in risk. Applying the utility functions of Kornhauser, the required compensation for an individual earning 200,000 per year can be estimated to be 1,650. The utility function $3 + 4 \cdot \ln(w + 1)$ was then applied for ex ante evaluation of utility in the injured state.

How much would an injured individual require in compensation after sustaining the injury? The answer depends on the assumptions made about the hedonic adaptation of the individual. If a substantial adjustment is assumed to take place, represented by the utility function $3 + 5 \cdot \ln(w + 1)$, the required compensation can be estimated as 97,650. This is considerably greater than the ex ante compensation for assuming the increased risk. If there is no hedonic adaptation, a staggering 6,752,500 would have to be added to original income (200,000) in order to restore the pre-injury level of utility. Thus, ex post compensation is considerably greater than ex ante compensation, no matter what assumptions are made regarding the hedonic adaptation of the injury victim.

Sen (1987, page 45) is critical of allowing for hedonic adaptation when trying to measure utility, stating that: “The hopeless beggar, the precarious landless labourer, the dominated housewife, the hardened unemployed or the over-exhausted coolie may all take pleasures in small mercies, and manage to suppress intense suffering for the necessity of continuing survival, but it would be ethically deeply mistaken to attach a correspondingly small value to the loss of their well-being because of this survival strategy."

The fact that a wheelchair user reports almost the same level of happiness as before the injury does not mean that the loss of functioning – the loss of capabilities – is insignificant. A case can therefore be made for using an instrument which measures functional capacity (like the Functional Capacity Index, see MacKenzie et al. 1996), rather than subjective utility, when assessing the value of preventing injuries that lead to significant permanent impairment.

8 CONFLICTS BETWEEN INDIVIDUAL AND COLLECTIVE RATIONALITY

An action is individually rational if it maximises individual utility. Factors influencing individual utility typically include income and health state, but may also include various altruistic motives. As far as road safety is concerned, however, behaviour tends to be self-regarding. The possibility therefore exists that behaviour gives rise to external effects that create a conflict between individual and collective rationality. Collective rationality is often defined in terms of Pareto-optimality. An action is Pareto-optimal if it improves the welfare of at least one individual without reducing it for anyone. In practice, few if any public policy actions are Pareto-optimal in this sense. A weaker criterion has therefore been proposed for cost-benefit analyses, that of a potential Pareto-improvement. A potential Pareto improvement refers to any change in which the gainers could in theory compensate the losers (in utility terms), while still retaining a net gain. This criterion is generally regarded as being satisfied when benefits (in monetary terms) exceed costs (in monetary terms).

Choices in which there is a conflict between individual and collective rationality are sometimes referred to as social dilemmas, because the choices that are best from a societal point of view (i.e. choices that are collectively rational) are not best from an individual point of view. Individuals will therefore tend to make choices that result in a sub-optimal state from a societal point of view.

Costs and benefits associated with the use of studded tires is an example of this. Several cost-benefit analyses of this measure have been made in Norway. One of these analyses, made by Christensen (1993) is particularly illuminating. The main results of the analysis are summarised in Table 6.

Cars having studded tyres have a lower accident rate than cars not having studded tyres. They are driven slightly faster, and owners tend to cancel fewer trips because of slippery roads. On the other hand, studded tyres cost more than standard tyres, and are associated with a small increase in fuel consumption. Still, from the road users' point of view, studded tyres make sense. Private benefits are greater than costs, so it is not surprising that many car owners opt for studded tyres.

Table 6 about here

The external impacts of studded tyres are, however, quite significant. Part of the benefit in terms of fewer accidents is an external benefit, since some of the costs of accidents are external from the road users’ point of view. However, studded tyres wear down roads. Moreover, the grinding of the road surface by the studs tears off particles, which are suspended in air and may impair health, in particular by worsening the condition of people who suffer from respiratory diseases. Inhalation of micro-particles may also lead to premature deaths. These external impacts are clearly negative. When impacts for road users and external impacts are added, losses are larger than gains. Although it is correct to include all external effects in a cost-benefit analysis, the fact that an identifiable group of road users perceive a net benefit, which is primarily driven by expected safety gain, creates a social dilemma. Car owners will prefer studded tyres, as the advantages are greater than the disadvantages. From a societal point of view, on the other hand, studded tyres should not be allowed.

9 INTERACTIONS INFLUENCING MARGINAL COST-EFFECTIVENESS

Road safety measures, for which cost-benefit analyses are made, are often part of a programme consisting of several measures. When several road safety measures are combined, their effects on safety interact in a way that can affect their net benefits (Elvik 2009A).

Consider the case of a policy maker who wants to introduce three road safety measures. One of them will reduce accidents by 30 %. The second measure will reduce accidents by 40 %. The third measure will reduce accidents by 50 %. What will be the total effect on accidents of introducing all three measures? The most common model used to estimate the combined effects of road safety measures is to assume that effects are independent and combine multiplicatively. Thus, in the example above, 70 % of accidents will remain once the measure that reduces accidents by 30 % has been implemented. Denote the effect of a measure by E, and the proportion of accidents the measure does not prevent by R, the "residual" of the measure. Both E and R are stated as proportions and sum to 1. Then, in the example above, the combined effect of the three measures is usually estimated as follows:

$$\text{Combined effect} = 1 - [(1 - E_1) \cdot (1 - E_2) \cdot (1 - E_3)] = 1 - (0.7 \cdot 0.6 \cdot 0.5) = 0.79$$

The combined effect of the three measures is an accident reduction of 79 %. This method of estimating combined effect can be referred to as the method of common residuals. Research by Elvik (2009A) suggests that this method may overestimate the combined effects of a set of road safety measures on the number of accidents. According to this research, a more correct method would be the following:

$$\text{Dominant common residuals estimate} = 1 - [(0.7 \cdot 0.6 \cdot 0.5)^{0.5}] = 1 - 0.46 = 0.54$$

The effect of the three road safety measures now becomes 54 %, as compared to 79 % when applying the common residuals method.

Imagine a programme consisting of four measures that influence the same accidents and have first order effects of 20 %, 15 %, 10 % and 5 %. It is further assumed that the benefit-cost ratio is identical for all the measures: 1.25. If the combined effect of the four measures is estimated by means of the dominant common residuals method, it becomes 0.648, or an accident reduction of 35.2 %. All else equal, the effects of the measures have now been reduced to such an extent that their benefits are now smaller than the costs. The benefit-cost ratio of each measures is now 0.88.

This means that the order in which measures are introduced can be decisive for their net benefits. Introducing measures in order of benefit-cost ratio is one option, but it is not necessarily the best one. The optimal order of implementation depends on whether there is indivisibility or irreversibility, i.e. on whether the implementation of a measure is a matter of all or nothing or a gradual process that can be taken in as many small steps as one wishes, and whether a measure can be reversed once a more cost-effective measure becomes available. An analysis of these possibilities is needed in order to determine the best order of implementation of road safety measures.

10 GAMES OF RESOURCE ALLOCATION EMBEDDED IN INCENTIVE STRUCTURES THAT UNDERMINE COST-EFFECTIVENESS

If public expenditures were fully based on cost-benefit analyses, the size of the budget would be perfectly adjusted to the size of the pool of measures whose (marginal) benefits exceed the (marginal) costs in any area of public policy. In practice, this is not how public budgets are determined.

In Norway, the allocation of public funds to provide public goods is guided by strong norms of equality that tend to undermine an efficient allocation. The operation of these norms can fruitfully be modelled as game-like situations. In some cases, the size and allocation of budgets are determined by means of a process of negotiation, or horse trading, resulting in a game-theoretic equilibrium that can be very stable and resistant to change. A case in point is the regional allocation of state funds for national road investments in Norway (Elvik 1995).

To illustrate this game, imagine that there are five voters. These five voters are faced by five issues, all to be decided by majority vote. Each issue is an investment project which is of particular concern for one of the voters, but less important for the other four. Table 7 shows the net benefits (+) and net costs (–) to each voter associated with each issue.

For voter 1, it is essential to ensure passage of issue 1. If issue 1, perhaps a local road investment project, is passed, voter 1 gets a net benefit of 10. Voter 2 takes a strong interest in issue 2, voter 3 in issue 3, and so on. The payoff matrix in Table 7 can be interpreted as a model of the provision of local public goods, funded by means of grants from the central government. Local road safety measures fit the description of local public goods. Since most traffic is local, the benefits are almost exclusively local, whereas the costs are spread among all taxpayers.

Table 7 about here

In order to ensure passage of issue 1, voter 1 needs the support of at least two other voters. The logic of the game of vote trading, or horse trading, is that: “I will vote for you if you vote for me”. Voter 1 therefore starts looking for other issues he might be able to support. Issue 2 is not very attractive. It is expensive, carrying a net cost of 8 to voter 1. Issues 3 and 5 are the most attractive ones to support for voter 1. Voter 1 therefore approaches voter 3, whose salient issue is issue 3, to ask for his support. As it happens, voter 3 considers voter 1 an attractive partner, since voting for issue 1 only costs voter 3 a loss of 6, whereas voting for issues 2 and 4 carries a price tag of 7 and 9, respectively, for voter 3.

By an analogous reasoning, voters 1, 3, and 5 agree to form a coalition to vote for issues 1, 3 and 5. For voter 1, the net benefit of this solution is: 10 – (3 + 4) = 3. For voter 3, the net benefit is: 15 – (6 + 5) = 4. For voter 5, the net benefit is: 10 – (2 + 2) = 6. Hence, all three voters in the coalition gain from the agreement and issues 1, 3 and 5 are passed by majority vote.

Society at large loses by this arrangement, however. At the bottom of Table 7 is shown the net benefits and costs to society of the five issues. It is seen that issues 2 and 4 have benefits greater than the costs, whereas for issues 1, 3, and 5, benefits are smaller than costs. If the budget were to be allocated according to a cost-benefit analysis, issues 2 and 4 would be funded. Issues 1, 3, and 5 would not be funded. However, if the budget is allocated according to a horse trading game, exactly the opposite happens.

A mechanism like this operates at several levels of government in Norway and results in an inefficient allocation of public funds. Thus, some counties have an abundance of funds for investments whereas other counties do not have sufficient funds to carry out all projects that have positive net benefits. Within each county or region, a similar game takes place to select sites for treatment on the road system (Elvik 2009B). Table 8 shows how this can result in inefficient selection of sites for treatment, using data for a Norwegian county as an illustration.

There are fifteen municipalities in the county. These differ greatly with respect to the size of the population and the volume of traffic on national roads in the municipality. Funds are available for constructing 20 roundabouts, each costing 5 million NOK for a total cost of 100 million NOK. The issue facing local politicians is where to construct these roundabouts.

Benefits can reasonably be assumed to be proportional to the number of cars per kilometre of road in each municipality. This is an indicator of traffic volume, and the more traffic, the greater are the benefits of a roundabout. Thus, benefits in municipality 1001 will be 3.75 times greater than the average for all municipalities, which has been set equal to 1. If selection of sites were based on efficiency, 8 roundabouts would be built in municipality 1001, 4 in municipality 1002, 2 in municipality 1003, 1 in municipality 1017 and 5 in municipality 1018. In the remaining 10 municipalities, no roundabouts would be built.

Table 8 about here

It is assumed that the conversion of junctions to roundabouts is funded by means of revenue from general taxation. This means that taxpayers in each municipality will pay a certain share of the cost of building roundabouts in that municipality, but that the rest of the cost is, in effect, paid by taxpayers in other municipalities, since general tax revenue is not hypothecated (i.e. raised and spent locally). In the county used as an example in Table 8, one municipality is considerably greater than the rest. Revenue from taxpayers in this municipality will pay 47 % of the cost of converting a junction to a roundabout – no matter which municipality the roundabout is built in.

The structure of funding, i.e. the percentage distribution of tax revenues originating in each municipality, is independent of where the roundabouts are built. Thus, for example, tax revenue generated in municipality 1037 will pay 3.4 % of the cost of building a roundabout no matter where it is built. If the roundabout is built in a different municipality, this will be an expense for no benefit to taxpayers in municipality 1037. If, however, the roundabout is built in municipality 1037, taxpayers get back part of their taxes in the form of benefits from one roundabout. In the case of municipality 1037, these benefits happen to be smaller than the expenditure – still it is better to get a roundabout than not to get one. Consequently, every municipality will prefer to get at least one roundabout rather than not getting one at all, because by getting a roundabout, taxpayers' money are not entirely wasted. The equilibrium solution to the game is therefore that one roundabout is built in each municipality. This makes for a total of 15 roundabouts. The remaining 5 roundabouts for which funds are available will be distributed among municipalities so that as many of them as possible get a favourable benefit-cost ratio from the municipal point of view.

This solution gives benefits that are greater than the effective costs to the municipality in eleven out of fifteen municipalities. A majority of the municipalities will therefore favour this solution. Thus, the majority of municipalities can blackmail the more populous and wealthy municipalities into accepting this selection for treatment.

An analysis by Fridstrøm and Elvik (1997) supports this conjecture. The analysis found that if a municipality has been selected for a road investment project, the probability that it would be selected once more was greatly reduced. Further support comes from data collected by Elvik and Rydningen (2002). These data show, among other things, that 313 road safety project were spread between 150 municipalities.

In the example given in Table 8, efficient selection for treatment results in an overall benefit-cost ratio for roundabouts of 2.55. If sites are selected for treatment according to the equilibrium solution to the game, overall benefit-cost ratio is reduced to 1.14. There is thus a significant loss of efficiency. However, this loss may not even be detected, since the overall benefit-cost ratio remains favourable even when sites are selected inefficiently.

11 DISCUSSION

The examples given in this paper show that basing policy priorities strictly on cost-benefit analysis, which in turn is based on the willingness-to-pay for non-market goods like improved road safety can lead to problems that the use of these tools were intended to solve, such as inconsistent policy priorities, unjustified preference reversals, wastage of public funds, and dissatisfaction with the results of policy.

The first two problems discussed can be avoided by basing choices on a fixed value per life saved, rather than a non-linear demand function. This is indeed the common practice and recommended in official guidelines for cost-benefit analysis. Thus, in Great Britain, the Treasury (2005) states that a single value of life should be used and differences in income and age should be ignored. It should be understood, however, that by using a single VSL-estimate one effectively ignores everything that influences WTP and applies a population average which may not necessarily reflect the preferences of most people or even a majority of the population.

The next two problems, concerning the intensity of preferences and priorities between the rich and the poor, may in principle be solved by assigning utility weights to income or individual willingness to pay. If costs and benefits are stated in utility terms, they will reflect the declining marginal utility of money. The trouble is that utility functions are not very well known and that some degree of smoothing may be needed to obtain utility functions that are mathematically tractable. The attractions of using logarithmic utility functions, as in the examples discussed in this paper, have been noted by several economists, including Kenneth Arrow (1965).

The difference between ex ante utility and ex post utility is inevitable in the sense that ex ante utility of a risky prospect reflects the fact that risk has not been resolved. Risk is resolved by the occurrence – or non-occurrence – of the event whose probability has been estimated ex ante. The lower the risk, the larger will be the difference between an ex ante compensation offered for exposing oneself to the risk, and the ex post compensation needed to restore pre-injury utility once the risk has materialised in the form of an injury. The real issue with respect to compensation ex ante versus ex post is whether any ex post compensation should adjust for hedonic adaptation among injury victims. On this issue, Sen has given strong arguments for not relying on subjective utility when assessing the quality of life for individuals who are obviously disadvantaged, whether in terms of reduced health or in terms of poverty and poor living conditions. He has advocated the use of an alternative approach, the capabilities approach, in which the quality of life is assessed in terms of what an individual has the capability to do. A closely related and practically applicable approach has been developed by MacKenzie et al. in the form of the functional capacity index.

Conflicts between individual and collective rationally may, at least to some extent, be eliminated by introducing road pricing. Thus, in the example used, the city of Oslo has introduced a tax for using studded tyres intended to reflect the external effects of using these tyres. External effects for which monetary valuations exist, can often be internalised by means of taxes or fees that reflect the damage done by the external effects.

As far as the path dependence of the benefit-cost ratio of road safety measures is concerned, the most important conclusion that can be drawn at this time is to conduct more research. The fact that some road safety measures are indivisible and that many are irreversible probably means that strict optimisation of the use of these measures is not possible. There has hardly been any research in this area.

The problems related to an inefficient allocation of public budgets are deeply rooted in the rules-of-the-game of the political system. These rules are not based on economic efficiency, but serve the important function of ensuring the legitimacy of the political system by giving the local level of government a strong influence on priority setting. This creates a system of negotiation and horse trading in which consensus or at least broad support for compromises is highly valued. One could argue that competing standards of rationality are involved here: What is the rational, i.e. benefit-maximising solution from the point of view of a local or regional government may not be benefit-maximising from a national point of view.

12 CONCLUSIONS

The following main conclusions can be drawn from the research discussed in this paper. In the first place, basing policy priorities for the provision of road safety strictly on individual willingness-to-pay for improved road safety does not ensure the consistency, or rationality, of priorities that advocates of the willingness-to-pay approach have suggested. On the contrary, strictly adhering to willingness-to-pay could make policy highly inconsistent by making it dependent on the factors that influence willingness-to-pay. In the second place, since the rich will normally be willing to pay considerably more for the provision of a given level of safety than the poor, a policy based strictly on willingness-to-pay may favour the rich. In principle, one may counteract this tendency by adjusting willingness-to-pay to account for the declining marginal utility of money. In practice, this is rarely done, but the use of a single common value-of-life will to some extent account for the problem, since such a common value will tend to be lower than the WTP-based value for the rich and higher than the WTP-based value for the poor. In the third place, individual utility, conceived of as subjective well-being (happiness, general satisfaction with life), depends not just on income but also on health state. Subjective utility is subject to strong hedonic adaptation. This means that even victims of severe injury will tend to report almost the same level of well-being as a person in perfect health. Since willingness-to-pay depends on subjective well-being, the high level of well-being reported by injury victims may imply a low willingness-to-pay for the prevention of the injuries. To counteract this tendency, one possibility is to determine health-related quality of life by scaling functional capacity. In the fourth place, there are poorly understood interactions between road safety measures, which could imply that it is not necessarily optimal to base the use of these measures strictly on marginal benefit-cost ratio. In the fifth place, cost-benefit analysis is always embedded in an institutional power structure that generates incentives that often favour the choice of other solutions than those implied by cost-benefit analysis.

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LIST OF FIGURES AND TABLES

Figure 1:

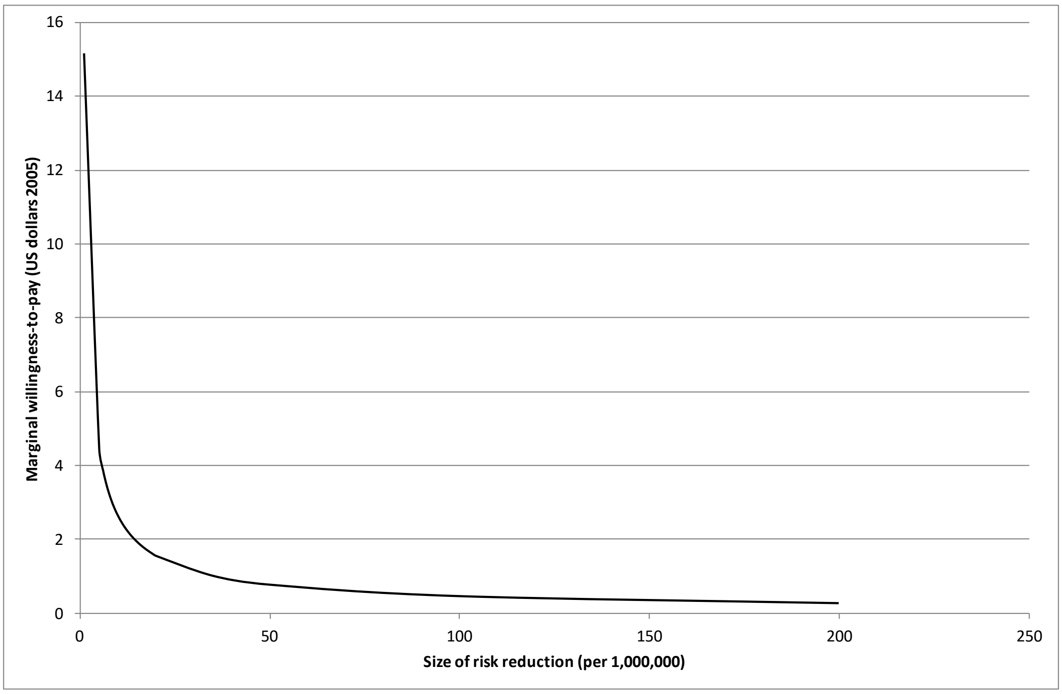


Figure 2:

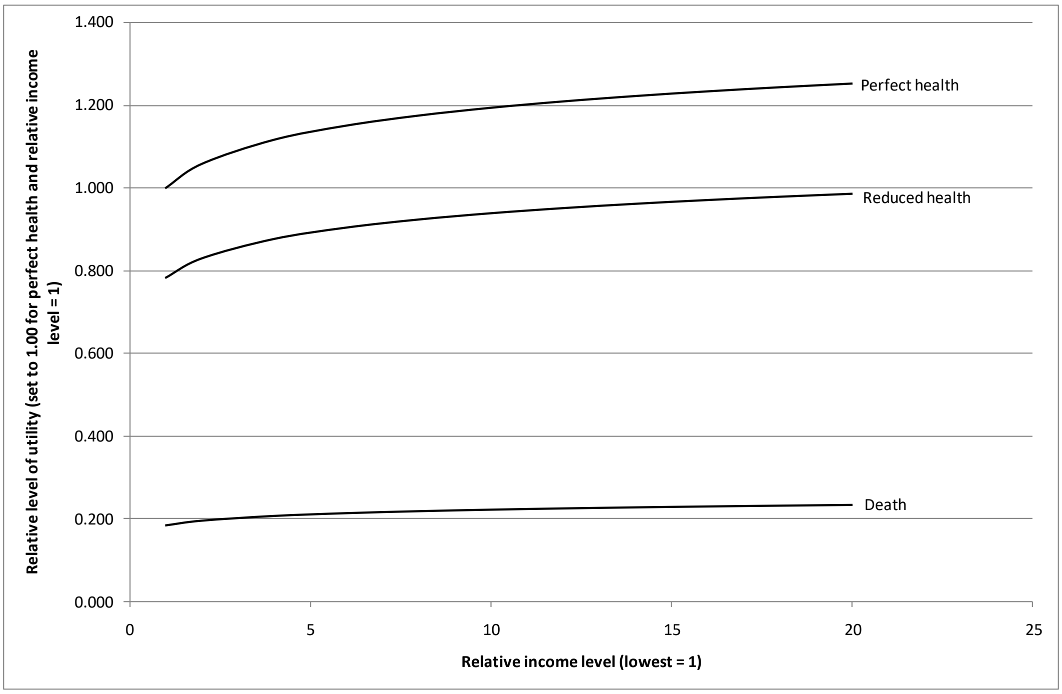
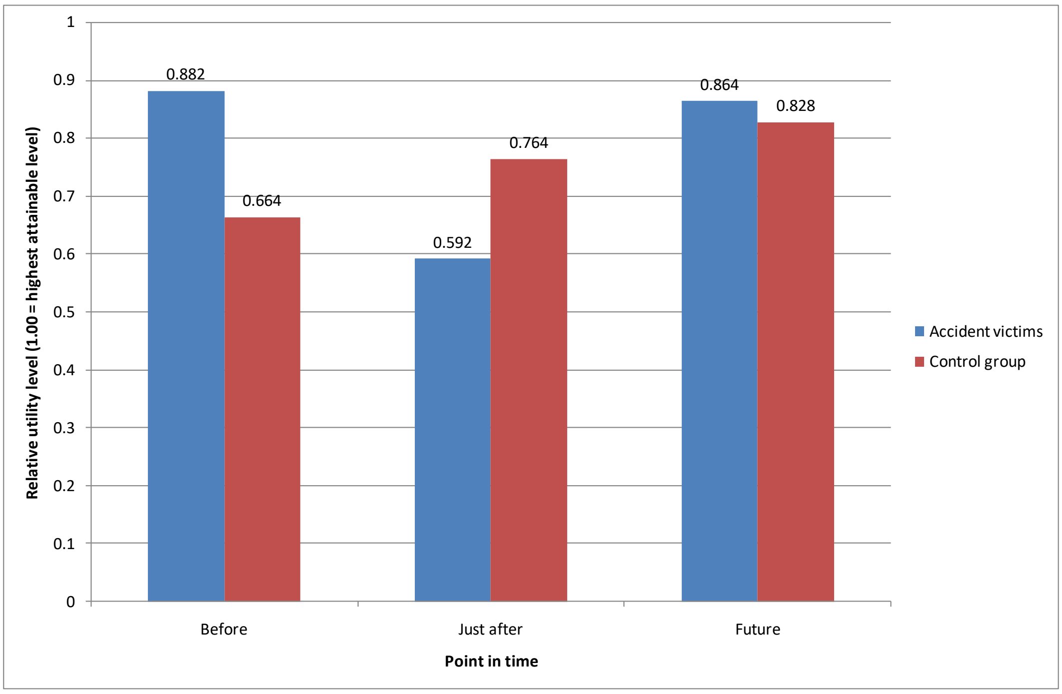


Figure 3:



1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Relative utility level (1.00 = highest attainable level)
0.882
0.664
0.592
0.764
0.864
0.828
Before
Just after
Future
Point in time
Accident victims
Control group

Table 1:

Risk reduction (per million)	Willingness to pay (US dollars 2005)	Marginal willingness to pay	Value of a statistical life (US dollars 2005)
1	63.38	15.15	63,376,490
5	93.11	4.45	18,621,386
10	109.88	2.63	10,988,241
15	121.06	1.93	8,070,914
20	129.68	1.55	6,484,020
50	161.43	0.77	3,228,583
100	190.51	0.46	1,905,146
200	224.84	0.27	1,124,202

Table 2:

Characteristics	Option A	Option B
Initial risk	20 in 1.000.000	20 in 1.000.000
Risk reduction	2 in 1.000.000	10 in 1.000.000
Size of population	10,000,000	2,000,000
Fatalities prevented	20	20
Benefit in monetary terms	748 million	220 million

Table 3:

Characteristics	Option A	Option B
Initial risk	20 in 1.000.000	20 in 1.000.000
Risk reduction	1 in 1.000.000	12 in 1.000.000
Size of population	10,000,000	2,000,000
Fatalities prevented	10	24
Benefit in monetary terms	634 million	230 million

Table 4:

Characteristics	Option A	Option B
Number of rich individuals	100	100
Number of poor individuals	900	900
Income per rich individual	500	500
Income per poor individual	50	50
Willingness-to-pay per rich individual	5	15
Willingness-to-pay per poor individual	2	1
Total willingness-to-pay – rich	500	1500
Total willingness-to-pay – poor	1800	900
Total willingness-to-pay – both groups	2300	2400
Share of income paid by the rich	0.01	0.03
Share of income paid by the poor	0.04	0.02
Relative aggregated willingness-to-pay – rich	1	3
Relative aggregated willingness-to-pay – poor	36	18
Total relative aggregated willingness-to-pay	37	21

Table 5:

Town	Group	Before	After	Mean WTP
A	Rich	2.97	2.86	950
	Poor	9.53	5.85	7845
B	Rich	2.10	1.93	1900
	Poor	6.05	5.25	1725

Table 6:

	Amounts in million NOK (1 NOK ≈ 0.12 EURO)	
Item	Gains (favourable impacts)	Losses (adverse impacts)
	Gains and losses to road users	
Accidents	132.5	
Travel time	53.1	
Additional trips made	5.0	
Costs of studded tyres		95.2
Fuel consumption		44.0
Total impacts	190.6	139.2
	Gains and losses external to road users	
Accidents	61.4	
Road wear		46.4
Air pollution		180.0
Total impacts	61.4	226.4
	Gains and losses for society as a whole	
Total impacts	252.0	365.6

Table 7:

	Issues				
Voters	1	2	3	4	5
1	+10	–8	–3	–7	–4
2	–9	+20	–13	–1	–8
3	–6	–7	+15	–9	–5
4	–2	–1	–7	+30	–3
5	–2	–3	–2	–7	+10
Total net benefits	10	20	15	30	10
Total net costs	19	19	25	24	20
Benefit–cost ratio	0.53	1.05	0.60	1.25	0.50

Table 8:

Municipality	Contribution to funding (%)	Cars per kilometre of road	Relative benefits of roundabout	Efficient selection for conversion	Municipal benefits to cost	Game equilibrium selection	Municipal benefits to cost
1001	47.06	285.8	3.75	8	3.19	3	1.19
1002	8.23	133.4	1.75	4	4.25	1	1.06
1003	6.17	90.4	1.19	2	1.92	1	0.96
1004	5.64	42.8	0.56	0	0.00	2	1.00
1014	7.67	73.4	0.96	0	0.00	1	0.63
1017	3.55	77.3	1.01	1	1.43	1	1.43
1018	6.26	162.6	2.13	5	8.52	1	1.70
1021	1.31	21.4	0.28	0	0.00	1	1.07
1026	0.51	30.9	0.41	0	0.00	1	3.98
1027	0.96	14.8	0.19	0	0.00	1	1.01
1029	2.61	36.6	0.48	0	0.00	1	0.92
1032	4.50	50.6	0.66	0	0.00	1	0.74
1034	0.97	22.2	0.29	0	0.00	1	1.50
1037	3.40	27.1	0.35	0	0.00	2	1.04
1046	1.16	12.4	0.16	0	0.00	2	1.40
Total	100	76.2	1.00	20		20	