Inferring the Value of Medical Research to the UK

by A.McGuire[1] and M.Raikou[2],

1. LSE Health, London
2. LSE Health, London and KEPE, Athens.

Contact details: Alistair McGuire, LSE Health and Social Care, Cowdray House J405, Houghton Street, London, WC2A 2AE. Tel: +44(0)20 7955 6375. E-mail: a.j.mcguire@lse.ac.uk

Acknowledgements: We would like to thank David Armstrong and Walter Holland for their comments on earlier versions of this paper. This work was funded in part by an educational grant provided by Pfizer Inc. UK.

1. Introduction

Continuing research and development is an important contributory factor to economic growth in any country. In 2001 the UK spent approximately 1.8% of GDP (£17.5 trillion) on research. As part of the government strategy to increase UK productivity a 10-year strategy was announced in 2004 with the UK Government was committed to increasing funding for R&D to 2.5% of GDP by 2014 with an average increase over the next 3-years of 5.8%. Medical research remains a major contributor to general UK R&D and, in particular is a major public sector activity in the UK. The absolute levels of medical research in the UK are considerable. Table 1 gives a breakdown of UK R&D medical research expenditure by different category of funding board from the year 1997/98 up to 2002/03 for the public sector (including non-profit making, charitable foundations). As can be seen by 2002/03 UK medical research by public bodies approached £2.5 billion. This public funding was approximately matched by UK pharmaceutical company R&D expenditure of £2.9 billion, of which approximately £250m is channelled through university research, to give a total annual investment of research funds in the UK health care sector of approximately £5.3 billion.[1] Internationally this makes the UK one of the largest contributors to medical research across the world.

With the government committed to increasing R&D expenditure health sector R&D is also set to grow. It is not surprising therefore that increasing attention is focussed on the returns from such funding. At least three levels of return to medical R&D can be distinguished: returns specified in terms of scientific knowledge; returns specified in terms of health benefits; and returns specified in terms of wider economic returns. The aim of this paper is to outline monetary estimates of the economic value of changes in UK life expectancy over the period 1970 to 2000, by drawing on a methodology proposed by Murphy and Topel (2003). In doing so this represents a first stage in attempting to attribute gains in longevity as a return to medical R&D. It is a first step for a number of reasons: first attributing all gains in longevity is not just heroic, it is obviously wrong. It is bound to overestimate a dimension of the gain. That said, gains in terms of morbidity are not considered at all and the attribution of return to medical R&D will be tempered in this respect. One justification for pursuing the approach is that it indicates the potential size of the return to medical R&D in a quantifiable manner. That said no precise value of the return is highlighted for a number of reasons, both conceptual and practical.

Table 1 Total Health Research and Development Expenditure (excluding profit making sector). £ Millions.

[1] The US scientific base of billion is used to represent 10^9 and trillion is used to represent 10^{12}. Traditional British use would denote 10^{12} as a billion. Harold Wilson, the Prime Minister of the UK, announced in 1974 that government statistics would conform to US standard usage with the term billion taken to mean 10^9 , and 10^{12} taken to be a trillion. It would appear he therefore devalued more than the pound sterling!

	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03
Higher Education Funding Councils						
HEFCE	204.2	219.4	238.3	243.7	249.9	255.5
SHEFC	25	26.7	27.1	27.5	28.6	34
HEFCW	6.7	8.1	8.7	9	10.6	9.2
DEL/NI	1.8	1.8	1.9	2.1	2.3	3.2
Research Councils						
BBSRC	83.8	89.4	94.1	98.7	93.1	103.4
MRC	315.8	310	339.5	362.9	423.5	434.5
Civil Departments						
NHS/DOH	426	420	434	448	475	506
DFID	42.2	47.6	81.2	123.7	99.3	168.3
Private Non-Profit (PNP)						
AMRC		418	544	632	594	660
WELLCOME		173	279	348	273	345
TOTAL		**1,714.0**	**2,047.8**	**2,295.6**	**2,249.3**	**2,519.1**

As an economic commodity R&D has a number of characteristics that may result in general underinvestment. In particular uncertainty and the public good nature of the commodity, where once knowledge has been released it becomes consumable by all, make the return to R&D high risk. Notwithstanding the inherently risky nature of R&D it has long been recognised that it is notoriously difficult to estimate the return to R&D (Arrow, 1962).With medical care research the problem is intensified in as much as with service-based industries the returns are difficult to capture. Many innovations are in the form of changes in process or techniques that can not be patented, making it difficult to for the private investor to capture the return. This return to R&D should be set in terms of increases to economic welfare. The difficulty becomes how to measure the increase in economic welfare. First R&D expenditure, even if the area of concern is limited to the health care sector, is heterogeneous. By definition there is both research and development; moreover research may be classified as basic or applied. Different types of spending on the different characteristics of R&D will result in different types of additions to economic welfare. In the area of health care the social benefit is especially difficult to quantify.

As well as conceptual problems there are practical concerns. Stoneman (2001) identifies at least three. First the issue of counterfactual evidence ought to be addressed. The measurement of the R&D policy requires evidence on what would have occurred if the policy had not been undertaken. In the case of R&D in the health care sector the obvious question is, given the impact of lifestyle and environment on health, what gains would have been achieved even without technical advances in medical care? Second, how should spillover effects, either the medical advances achieved elsewhere the gains from which are realised in the UK or the returns achieved in other settings from UK R&D, be accounted for? The public good nature of research, essentially through the dissemination of knowledge, makes it most susceptible to these external

effects. Third there is the issue of the time span over which the effects should be measured. Health benefits may have an effect over generations for example.

Despite the acknowledgement of such conceptual and practical issues a recent paper by Murphy and Topel (2001) attempted to indicate the value of medical R&D to society through considering the impact that medical research has had on health, specifically mortality rates by age and sex, by estimating the monetary value that society places on the health gains achieved through increased longevity. The Murphy and Topel (op. cite.) paper was based on US data. This paper draws on the methodology used by Murphy and Topel to give broad estimates of the magnitude of the return to UK medical research over the period 1970 to 2000 as based on the value of longevity achieved over this period. To do so assumptions similar to the Murphy and Topel study are made but UK data are used to indicate UK specific values of the return to medical R&D.

One practical issue, as noted above, is the choice of timeframe. The health of the UK population has been improving markedly for a long period. Crude mortality rates for various diseases exhibit marked declines as shown by Figure 1 with consequent improvement in life expectancy. The most remarkable decline has been with respect to circulatory diseases, even though this remains the most common cause of death. Cancers are now the second most common cause of death in England and Wales, but even here there has been a slight decline in mortality rates over the last 10-years. It is undoubtedly true, for example that major pharmacological and surgical innovations, including the introduction of beta-blockers, ACE inhibitors, statins and diuretics as well as the introduction of angioplasty and stenting have had a marked impact on morbidity and mortality arising from circulatory diseases, but so too has the change in smoking habits. While undoubtedly arbitrary, 1970 is taken as the starting point for the analysis as it was during this decade that the first major treatment improvements with respect to heart disease were introduced.

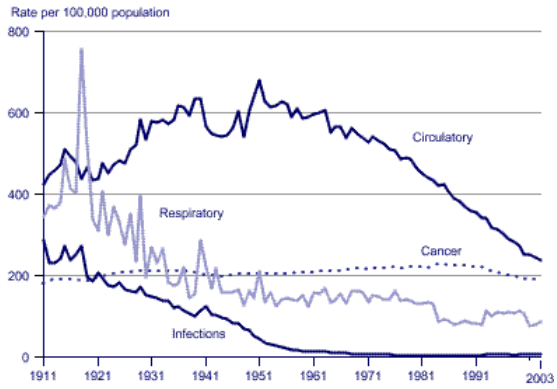


Figure 1. Common causes of death in England and Wales. Mortality rates 1911-2003. Source: ONS

The paper is structured as follows. The next section discusses the basic methodological approach used to value changes in life expectancy in some detail. This is then followed by the

basic results gained from our UK calculation. A discussion of limitations and potential improvements on the approach then follow.

2. Methods

The basic approach adopted by Murphy and Topel draws on an established literature which forwards estimates of individuals' willingness-to-pay (WTP) for reductions in mortality risks which can then be converted into an estimate of the value of a statistical life (Viscusi and Aldy, 2003). The fundamental idea is to assume that individuals would be willing to pay a monetary sum to reduce the risk of mortality. Estimates of the values attached to reductions in these risk levels extrapolate to an estimate of the value of a (statistical) life. This literature has a long history (Mishan, 1971) and the concept can be outlined as follows. The standard derivation of the value of a statistical life derived from revealed preferences may be given as

$$\frac{dW}{dp} = \frac{u_a(W) - u_d(W)}{(1-p).u_a^{'}(W) + p.u_d^{'}(W)}$$

where W is wealth, p is the probability of death in the current period (the baseline risk), *(1-p)* is the probability of surviving the current period, *u* is utility, *a* is survival and *d* is death. The utility function u_d allows for bequests on death. The numerator shows the difference in dying and surviving the current period. The denominator shows the marginal utility of wealth conditional on survival or death. Such values may be calculated for different ages and extended over time and discounted back to the present using present value techniques.

This simple formulation of the WTP for changes in the risk of dying is premised on the utility gained from wealth under different mortality risks. The concept of the value of a statistical life has been traditionally formulated in this manner with much empirical work, based largely in the USA, deriving values of the WTP for changes in the risk of death from observed differences in the income levels associated with risky, (in terms of risk of death), and low risk occupations (Viscusi and Aldy, 2003). The associated empirical literature produces a range of estimates that involve implicit tradeoffs between mortality risk and wealth, essentially calculating the average marginal rate of substitution of wealth for risk, in a number of different circumstances. Most of these estimates have been based on the so-called compensating variation required by individuals to undertake risky tasks in the labour market with most analyses having been undertaken in the USA. The extension to calibration with wealth is obvious. The formulation can however be changed to calibrate WTP for changes in mortality risk with utility levels, (i.e. measures of individual welfare), derived from consumption and leisure activities with the basic idea being that individuals derive utility not from wealth per se but from the use of wealth in consumption and leisure activities. Again this calibration can be performed for different ages and across different time periods. The approach adopted below extends this empirical literature through an adaptation

based on Murphy and Topel (2003), utilising the calibration of WTP for reduced mortality risk with the utility derived from lifetime consumption and leisure.

The empirical literature produces a range of estimates of WTP for reduction in mortality risk that involves implicit trade-off between mortality risk and wealth, essentially calculating the average marginal rate of substitution of wealth for risk, in a number of different circumstances largely based on the so-called compensating variation required by individuals to undertake risky tasks in the labour market with the majority of analyses having been undertaken in the USA. Such estimates were used as an essential component of the Murphy and Topel calculation. It is well recognised however that there are limitations to this approach. The most obvious drawback is that such estimates are based on implied trade-offs gained from individuals of working age. It is also accepted that future life expectancy will affect the value of a statistical life. Age obviously affects the duration of life at risk but may also be correlated with other factors, including changes in preferences, which will affect an individuals' WTP to for changes in survival probability. Moreover non-pecuniary aspects of work will be omitted from such labour market based calculations. Injury risk may also be correlated with mortality risk and the implied estimated gained from labour market studies may be biased because of the lack of inclusion of this injury risk. Indeed even individual characteristics, such as clumsiness, may affect the estimates gained from implicit trade-offs based on labour market studies. Moreover given the expected positive income elasticity with respect to the value of risks to an individual's life, it might be predicted that estimates gained from studies conducted in the USA would have a tendency to be higher than in other countries, given the higher average earnings of workers in the USA compared to other countries. Indeed a recent review of the literature on the value of a statistical life found that UK studies estimate compensating differentials which are "implausibly large" and of the order of 10 percent of wage income compared to the 1 to 2 percent of wages found for the USA (Viscusi and Aldy, 2003).

Given these implausible values and the fact that the UK literature on the WTP for reduction in mortality risk literature has been dominated by a related but different methodology a different WTP approach forms the basis of the analysis presented here. UK measures of the WTP for changes in mortality risk, and subsequent valuation of a statistical life, have been based upon contingent valuation studies which use direct questionnaire based methods to elicit explicit trade-offs between wealth and safety. The resultant monetary values of individuals' WTP to reduce the risk of fatalities, accidents and morbidity are used by UK governmental departments to assist in the calculation of the costs and benefits of various public sector funded projects. Thus as reported by Chilton et al (2002) the value of the prevention of a statistical fatality used by the Department of Transport in evaluating public sector road projects has been based on

questionnaire based preference elicitation techniques to calculate the value of safety which is then used to estimate the value of a change in the probability of survival. The current value of a statistical life used by the Department of Transport as based on preference elicitation techniques for example is £1.14 million (2000 prices).

Recent attempts to re-estimate these values in the UK have focussed on relative valuations of the WTP for reduction in mortality risk in different settings (Chilton et al, 2002). This recent work recognises that various aspects of individual decisions may affect the preference based valuations of risk of death when these risks are assessed in different contexts. Thus issues of control over the circumstance, dread and expectation could affect the elicited valuation. Indeed the UK Health and Safety Executive (HSE) has used an estimate of the value of a statistical life which is double the Department of Transport estimate for cancer-related fatalities to incorporate an individual fear of this particular disease (Andrews and McCrea, 1999). That said, most empirical work suggests that individual estimates of the value of a statistical life do not significantly differ across different settings (Chilton et al, 2002). The relative valuation approach also recognises that small absolute risk values, as used in calculations where circumstances were such that low absolute risk values formed the basis of the calculation as death was rare in the examples used, may lead to error in the direct estimation of willingness-to-pay (WTP) values for changes in survival probability. Typically such estimates of WTP are calculated by dividing mean reported WTP estimates for a given reduction by the risk reduction itself. Where this is the case even small miscalculation of the WTP response by respondents will lead to over-estimation of the WTP. The relative value approach uses an estimated relative value ratio of, for example, risk of death from road and rail travel in conjunction with the (relatively high) absolute risk of death from road travel to overcome this. This approach is similar to the “person trade-off” methodology adopted by Nord (1992) and suggested as a means of estimating the relative values of specific health care interventions.

Using as a base the estimated value of a UK statistical life set at £1.14 million, the analysis continues by assuming that medical research leads to further improvement in individual survival probabilities that may be given a monetarised value based on this estimated value of a statistical life[2]. The basic approach sees an individual trying to maximise their own welfare through enjoying consumption and non-market activities over a healthy lifetime; individuals derive utility from consumption and leisure the benefits from which may be estimated over their lifetime in terms of a discounted monetary equivalent sum. The estimation of the value of a gain in survival time is

[2] The value of a statistical life is normally gained from contingent valuation questions which relate to questions based on risks in mortality around 1/10,000 or 1/100,000 (Jones-Lee et al, 1995). So the value of a statistical life can be re-based into a change in a small risk. In our case a change in mortality risk of 1/10,000

calculated by ignoring non-healthy time; that is by assuming that a gain in life expectancy is of value in itself regardless of how healthy the individual is with improved life expectancy. To the extent that an individual will pay more for improved health as well as life expectancy the estimated value of a gain in survival time is therefore conservative. Any WTP for a gain in survival time must then be equal to the utility gains enjoyed from improved life expectancy; the marginal costs defined in terms of WTP must equal the marginal benefits defined in terms of utility gain. Thus an estimated WTP for a stated reduction in annual mortality risk, taken from the UK literature based on the normalised value of a statistical life, is set equal to full lifetime consumption, amended for any surplus gained from any preference for consumption at given points in an individuals life cycle, further weighted by changes in life expectancy. That is, the marginal cost in terms of WTP for additional survival is equal to the marginal benefit in terms of additional utility gained from additional life expectancy controlling for consumption and saving preferences over an individual's lifetime.

A standard individual lifetime utility maximising model is then the starting point for the Murphy and Topel model. This can be represented, using their notation, as:

$$V = \int_0^{\infty} e^{-pt} H(t) u(c(t), l(t)) S(t) dt \qquad [1]$$

Where *V* is the expected lifetime utility of an individual and is given as the discounted gains (with the discounting given as e^{-pt}) derived from the consumption (*c(t)*) and non-market (*l(t)*) activities enjoyed over healthy (*H(t)*) survival time (*S(t)*). Ignoring the health status aspects of changes in life expectancy and assuming that life cycle preferences can be modelled as a given surplus of present consumption over lifetime consumption then the WTP for improved longevity may be expressed as:

$$\frac{dV}{\mu} = \int_0^{\infty} e^{-rt} \phi C_F(t) \Delta S(t) dt \qquad [2]$$

where $\frac{dV}{\mu}$ is the WTP for improved longevity which is equal to the discounted (at a constant rate *r*) value of the additional survival gains ($\Delta S(t)$) valued in terms of the life time consumption of market and non-market activities (the monetary value of consumption and leisure activities ($C_F(t)$)) weighted by the value of life cycle preferences to the individual (θ) . This general equation can be evaluated at different ages and set equal to a pre-defined WTP for a given reduction in the probability of death ($W(a)\lambda$) to give the WTP for improved longevity at age *a* ($\frac{dV(a)}{\mu(a)}$) as:

$$\frac{dV(a)}{\mu(a)} = \lambda \int_{a}^{\infty} e^{-r(t-a)} \theta C_F(t) \frac{S(t)}{S(a)} dt = \lambda W(a) \quad [3]$$

where all terms are as before with the exception that the additional survival gain is from age *a* and the change in longevity is defined as $\frac{S(t)}{S(a)}dt$ and λ is the pre-specified magnitude of the reduction in the mortality rate.

Assuming that the improvement in longevity is attributable to both improvements in medical knowledge and health care itself then the gain to an individual who has survived to age *a* from improvements in medical knowledge through medical research, can be given as:

$$V_R(a,R) = \int_{a}^{\infty} e^{-r(t-a)} S_R(a,t,R,Z) \theta C_F(t) dt \quad [4]$$

where $V_R(a,R)$ is the value of the gain in medical research (*R*) to an individual aged *a*, $S_R(a,t,R,Z)$ is the gain in longevity for an individual aged *a* attributable to medical research (*R*) and health care (*Z*), and all other terms are as before. Accepting that this equation is linear in the change in survival function renders a discrete version amenable to empirical investigation as:

$$V_2 - V_1 = -\int_{a}^{\infty} e^{-r(t-a)} [S_2(t) - S_1(t)] \theta C_F(t) dt \quad [5]$$

where $S_1(t)$ and $S_2(t)$ are two survival functions evaluated at age *a* which encompass the gains in longevity achieved from medical research and health care. Finally this value of increased longevity can be aggregated up from the individual level to the population level through simple addition across individuals such that the population gains are given as:

$$V_R(t) = \sum_{a=0}^{T} N(a,t) V_R(a,R) \quad [6]$$

where *N(a,t)* is the number of individuals of age *a* at date *t*, and V_R refers to the function given in equation [5].

This gives the basic methodological framework draws heavily on and replicates the Murphy and Topel (2003) approach to allow an indication of the possible value of medical research to any given population calculated through WTP for a reduction in mortality risk and the utility benefits gained from increased longevity. Of course a number of assumptions have been made to make this method operational. First a time period has to be specified. In this paper the period 1970 to 2000 is considered. This is arbitrary but coincides with large mortality declines in the UK population from various diseases, most notably coronary heart disease. Second gains in health

from medical research are calculated having taken account only of any contemporaneous gains attributable to health care. Any health gains from lagged health care effects, changes in individual behaviour or from changes in environmental conditions are not estimated with the possible inference that there is over-estimation of the benefits from medical research. On the other hand any health gains attributable to medical research resulting in changes in morbidity and quality of life are not calculated thereby underestimating the return to medical research.

3. Empirical Results

The empirical results relate to the period 1970 to 2000. The estimates of the WTP are calculated for 3 sub-periods, (1970-1980; 1980-1990; 1990-2000), and then aggregated for the full period 1970-2000. To gain empirical estimates the investigation proceeds as follows. First estimates of the WTP for changes in the probability of survival are gained from equation (2) in order to estimate θ. This is based on the equation

$$\frac{dV(a)}{\mu(a)} = \lambda \int_{a}^{\infty} e^{-r(t-a)} \theta C_F(t) \frac{S(t)}{S(a)} dt = \lambda W(a) \qquad [7]$$

Which is defined above and relates WTP to changes in survival probability. As Murphy and Topel note *W(a)* is commonly referred to as the "value of a statistical life" when λ is set equal to 1. However empirical estimates of the WTP for changes in survival probability are normally gained when λ is set to a value less than 1 or when individuals are requested to provide information on WTP for values of λ is set to a value less than 1. That said as noted above the current value of a statistical life used by the UK Department of Transport as based on preference elicitation techniques for example is £1.14 million (2000 prices) and this forms the basic input into the WTP equation.

The calculation also requires estimates of life cycle consumption, $C_F(t)$. This is gained, as in the Murphy and Topel study, through a proxy based on male lifetime earnings. This was taken from an ONS/DTI study on individual income (ONS, 2004) which reported the median income by age band for men and women in 2003/04. The relevant figures, based on net median weekly income for men, are reported in Table 1 and taken as a proxy for lifetime consumption[3]. Finally a discount rate of 3.5% is used.

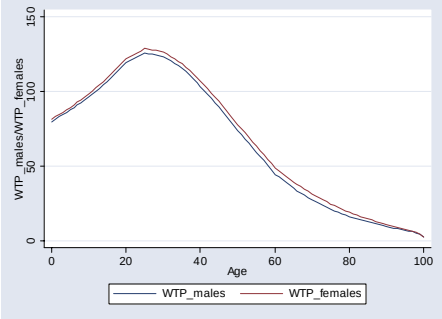
[3] This follows the same assumption as Murphy and Topel that full income is proportional to lifetime income profile and is captured by a representative earnings profile. The earnings profile is extended to those younger than 16 by assuming their median "income" is the same as for the 16-19 year olds.

Table 1

Age	Annual Median Income, Males 2003
16-19	£5,096
20-24	£10,712
25-30	£17,160
30-34	£20,540
35-39	£21,996
40-44	£21,944
45-49	£21,840
50-54	£19,188
55-59	£17,784
60-64	£13,104
65-69	£11,128
70-74	£10,296
75-79	£9,308
80-84	£8,632
85+	£8,736

Substitution of the relevant estimates into equation 2 and solving for θ results in an estimate of 2.89. Figure 3 reports the resultant life cycle profile for an individual's WTP for a 1/10,000 reduction in contemporaneous mortality risk for men and women based on the value of a statistical life set at £1.14 million (the y-axis measures WTP in £s; the x-axis measures age). This life cycle estimate of full income allows calculation of the monetary value of further reductions in mortality risk attributable to R&D.

Figure 3 Value of a reduction of a 1/10,000 risk of mortality by age (£2000 prices)



This calculation of the WTP for changes in survival probability at the individual level can be used to consider the change in life expectancy attributable to medical research and the level of health care expenditures at the population level. Following Murphy and Topel the increased value in life expectancy is estimated through the following equation, with the definitions as given above [eq. 5]:

$$V_2 - V_1 = -\int_a^{\infty} e^{-r(t-a)}[S_2(t) - S_1(t)]\theta C_F(t)dt \qquad [8]$$

The value of increased longevity can be aggregated up from the individual level to the population level through simple addition across individuals such that the population gains are given as:

$$V_R(t) = \sum_{a=0}^{T} N(a,t)V_R(a,R) \qquad [9]$$

To implement these equations an estimate of θ is required (obtained as 2.84 from the calculation above), and the two survivor functions *$S_1(t)$ and $S_2(t)$* to be compared. For all calculations the base year population is taken from the year 2000 and the discount rate is taken as 3.5%.

Figures 4 and 5 show the results in terms of the estimated per capita gains in monetary terms associated attributable to medical research associated with improved UK survival functions for the periods 1970-1980; 1980-1990; 1990-2000. The graphs cumulate the per capita gains in each period so that the total height of the graph reports the total per capita gains in reduced mortality over the whole period 1970-2000. The monetary measurement of the gains in individual survival over the period are substantial. Improvements in life expectancy over the total period peak for men around the age of 60 at approximately £90,000, while for women they peak at around £60,000 at 65 years of age.

Figure 4 Gains from increased survival probability: men

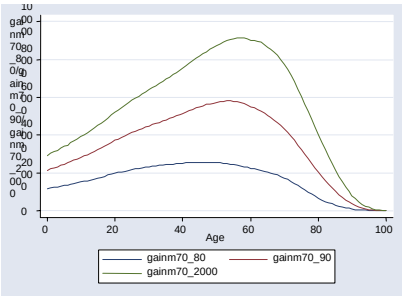


Figure 5. Gains from increase survival probability: females

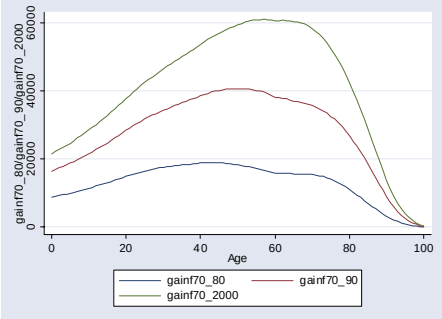


Table 2 reports the gains in economic welfare from medical research for the periods 1970-1980; 1980-1990; 1990-2000 and over the whole period 1970-2000 and forms the basic results. The Table shows the gains by age group for the various sub-periods for males and females. The table also shows the aggregate gains. As can be seen the gains are substantial. Over the whole period the gains are approximately £2.84 trillion. This is approximately double the current yearly GDP of the UK. The gains are greatest for the period 1980-1990.

Table 2 Economic gains from reduction in mortality by age attributed to medical research

Males	**Aggregate Gains (£2000)**		
Agegroup	**1990-2000**	**1980-1990**	**1970-1980**
Birth	£2,480,000,000	£3,010,000,000	£3,610,000,000
1-4	£11,300,000,000	£13,700,000,000	£16,300,000,000
5-9	£17,200,000,000	£20,600,000,000	£24,200,000,000
10-14	£20,300,000,000	£23,900,000,000	£27,800,000,000
15-19	£22,000,000,000	£25,700,000,000	£29,500,000,000
20-24	£23,800,000,000	£27,600,000,000	£31,200,000,000
25-29	£30,900,000,000	£35,400,000,000	£39,000,000,000
30-34	£39,300,000,000	£44,400,000,000	£46,900,000,000
35-39	£44,700,000,000	£49,900,000,000	£49,500,000,000
40-44	£44,500,000,000	£49,000,000,000	£45,100,000,000
45-49	£45,800,000,000	£49,600,000,000	£41,800,000,000
50-54	£55,500,000,000	£58,000,000,000	£44,400,000,000
55-59	£48,700,000,000	£47,600,000,000	£33,800,000,000
60-64	£45,000,000,000	£39,900,000,000	£27,400,000,000
65-69	£39,200,000,000	£31,300,000,000	£21,400,000,000
70-74	£30,100,000,000	£22,400,000,000	£14,400,000,000
75-79	£18,500,000,000	£13,100,000,000	£7,310,000,000

80-84	£6,690,000,000	£4,440,000,000	£2,060,000,000
85-90	£1,690,000,000	£1,050,000,000	£431,000,000
90+	£111,000,000	£59,900,000	£27,800,000
Total	£547,771,000,000	£560,659,900,000	£506,138,800,000
Females			
Agegroup	**1990-2000**	**1980-1990**	**1970-1980**
Birth	£1,500,000,000	£2,230,000,000	£2,580,000,000
1-4	£6,820,000,000	£10,100,000,000	£11,700,000,000
5-9	£10,300,000,000	£15,200,000,000	£17,300,000,000
10-14	£12,200,000,000	£17,700,000,000	£19,900,000,000
15-19	£13,300,000,000	£19,300,000,000	£21,400,000,000
20-24	£15,200,000,000	£21,800,000,000	£23,900,000,000
25-29	£20,400,000,000	£28,700,000,000	£30,600,000,000
30-34	£25,900,000,000	£35,600,000,000	£36,400,000,000
35-39	£29,000,000,000	£38,800,000,000	£37,900,000,000
40-44	£28,500,000,000	£36,700,000,000	£34,000,000,000
45-49	£29,200,000,000	£36,100,000,000	£31,100,000,000
50-54	£35,200,000,000	£40,800,000,000	£32,200,000,000
55-59	£31,100,000,000	£33,100,000,000	£24,300,000,000
60-64	£29,700,000,000	£28,600,000,000	£20,700,000,000
65-69	£27,800,000,000	£25,000,000,000	£18,700,000,000
70-74	£24,500,000,000	£22,200,000,000	£17,000,000,000
75-79	£19,100,000,000	£18,400,000,000	£13,600,000,000
80-84	£9,540,000,000	£9,970,000,000	£6,680,000,000
85-90	£3,790,000,000	£4,360,000,000	£2,530,000,000
90+	£460,000,000	£552,000,000	£317,000,000
Total	£373,510,000,000	£445,212,000,000	£402,807,000,000

Total gains (males)	**£1.61 trillion**
Total gains (females)	**£1.22 trillion**
TOTAL	**£2.84 trillion**

To this point the economic return arising from improved survival has been calculated without consideration to health care expenditure. Of course over the time period under consideration there have been improvements in the delivery of health care. The surival return net of health care can be calculated through removing the impact of health care expenditure. This is estimated, again following Murphy and Topel, through the following equation

$$\Delta V^{N}(a) = -\int_{a}^{\infty} e^{-r(t-a)}[S_2(t) - S_1(t)]\theta C_F(t)dt - \int_{a}^{\infty} e^{-r(s-a)}S^{*}(s)\Delta X(s)ds \qquad [10]$$

Where all the terms are defined above with the exception of $S^{*}(s)$ which denotes the survival function fixed at year 2000 levels, and $\Delta X(s)$ is the increase in real expenditures at a given age *a*, and the net gain from medical research at age *a* is $\Delta V^{N}(a)$. The $\Delta X(s)$ is the increase in real expenditures at a given age *a* is based on the real (in 2000 prices) per capita health care expenditures for the relevant years. These per capita figures were given an age profile by adjusting by the age breakdown of per capita health care expenditures in 2004 for the age groups 0-4, 5-14, 15-44, 45-64, 65-74, 75-84 and over 85.

Table 3 reports the results and as can be seen the overall total economic gain remains substantial, at £2.58 trillion even after netting out the growth in health care expenditures over the period 1970-2000.

Table 3 Gains from reduction in mortality by age attributed to medical research net of health care expenditure growth

Males	**Aggregate Gains (£2000)**		
Agegroup	**1990-2000**	**1980-1990**	**1970-1980**
Birth	£824,000,000	£2,110,000,000	£2,760,000,000
1-4	£4,410,000,000	£9,900,000,000	£12,800,000,000
5-9	£14,400,000,000	£19,000,000,000	£22,800,000,000
10-14	£17,500,000,000	£22,400,000,000	£26,400,000,000
15-19	£18,300,000,000	£23,700,000,000	£27,700,000,000
20-24	£20,500,000,000	£25,800,000,000	£29,500,000,000
25-29	£27,300,000,000	£33,400,000,000	£37,100,000,000
30-34	£35,300,000,000	£42,200,000,000	£44,800,000,000
35-39	£40,900,000,000	£47,800,000,000	£47,500,000,000
40-44	£41,300,000,000	£47,300,000,000	£43,500,000,000
45-49	£41,500,000,000	£47,300,000,000	£39,600,000,000
50-54	£51,400,000,000	£55,700,000,000	£42,300,000,000
55-59	£45,800,000,000	£46,100,000,000	£32,300,000,000
60-64	£42,800,000,000	£38,700,000,000	£26,300,000,000
65-69	£35,500,000,000	£29,300,000,000	£19,500,000,000
70-74	£27,800,000,000	£21,200,000,000	£13,300,000,000
75-79	£16,500,000,000	£12,000,000,000	£6,300,000,000
80-84	£6,110,000,000	£4,120,000,000	£1,760,000,000
85-90	£1,470,000,000	£931,000,000	£322,000,000
90+	£99,400,000	£53,400,000	£21,700,000
Total	£489,713,400,000	£529,014,400,000	£476,563,700,000
Females			
Agegroup	**1990-2000**	**1980-1990**	**1970-1980**
Birth	-£107,000,000	£1,350,000,000	£1,760,000,000
1-4	£128,000,000	£6,470,000,000	£8,230,000,000
5-9	£7,600,000,000	£13,700,000,000	£15,900,000,000
10-14	£9,460,000,000	£16,300,000,000	£18,500,000,000
15-19	£9,680,000,000	£17,300,000,000	£19,500,000,000
20-24	£11,700,000,000	£19,900,000,000	£22,100,000,000
25-29	£16,400,000,000	£26,500,000,000	£28,500,000,000
30-34	£21,500,000,000	£33,200,000,000	£34,200,000,000
35-39	£24,900,000,000	£36,500,000,000	£35,700,000,000
40-44	£25,000,000,000	£34,900,000,000	£32,200,000,000
45-49	£24,500,000,000	£33,500,000,000	£28,600,000,000

50-54	£30,500,000,000	£38,200,000,000	£29,700,000,000
55-59	£27,700,000,000	£31,200,000,000	£22,500,000,000
60-64	£27,100,000,000	£27,100,000,000	£19,300,000,000
65-69	£22,700,000,000	£22,300,000,000	£16,100,000,000
70-74	£20,800,000,000	£20,200,000,000	£15,100,000,000
75-79	£15,000,000,000	£16,100,000,000	£11,500,000,000
80-84	£7,850,000,000	£9,050,000,000	£5,810,000,000
85-90	£2,820,000,000	£3,830,000,000	£2,030,000,000
90+	£360,000,000	£497,000,000	£266,000,000
Total	£305,591,000,000	£408,097,000,000	£367,496,000,000

Total gains (males)	**£1.5 trillion**
Total gains (females)	**£1.08trillion**
TOTAL	**£2.58trillion**

Following Murphy and Topel calculations are made of the monetarised gains that would be established if R&D in medical care gave rise to a further 1% and 10% fall in the probability of death from major diseases. Using the basic approach of equation 8 and applying this to the range of diseases defined in the tables the results are shown in Tables 4 and 5. For a 1% fall in the defined diseases a total of £3,000 million in economic welfare would be achieved from such a reduction, with the largest gains being achieved through improving life expectancy associated with heart disease and the gain arising from improvements in the area of cancer. These results are replicated for a 10% fall and a 100% fall. Focussing on the 10% the calculations from Table 5 show the total gain would be £37,000 million with heart disease and diseases relating to malignant neoplasms again being the largest contributors. The prospective gain in mortality from heart disease being reduced by 10% being close to £8,000 million. Of course while such gains assume no diminishing returns to health investments in these areas, they are nevertheless impressive.

Table 4. Prospective gains from a permanent 1% reduction in death rates by major cause of death

	Males	Females	Total
All causes	**2,030,877,524**	**1,672,899,141**	**3,703,776,665**
Infectious and parasitic diseases	11,750,601	10,029,363	21,779,964
Diabetes mellitus	12,777,009	12,388,204	25,165,213
Pneumonia & influenza	89,442,215	108,440,513	197,882,728
Chronic liver disease and cirrhosis	22,699,221	13,737,527	36,436,747
Chronic obstructive pulmonary disease and allied conditions	62,268,067	49,121,157	111,389,224
Malignant neoplasms	348,751,319	319,532,484	668,283,802
Malignant neoplasm of digestive organs and peritoneum digestive organs	103,699,269	74,552,906	178,252,174
Malignant neoplasm of trachea, bronchus and lung respiratory	90,341,273	54,689,359	145,030,632
Malignant neoplasm of female breast	0	64,211,175	64,211,175
Malignant neoplasm of genitourinary organs	56,743,386	48,800,857	105,544,243
Major cardiovascular disease	559,535,860	439,464,320	999,000,180
Diseases of the heart	469,229,898	319,233,242	788,463,140
Cerebrovascular disease	82,972,850	113,666,039	196,638,889
Accidents and adverse effects	55,450,025	24,359,230	79,809,255
Motor vehicle traffic accidents	24,146,419	7,448,706	31,595,125
Homicide and injury purposely inflicted by other persons	2,054,339	1,118,714	3,173,053
Suicides and injury undetermined whether accidentally or purposely inflicted	39,015,775	12,105,345	51,121,120

Notes: Sub-categories are not exclusive and therefore do not total to the figures given in major categories

Table 5. Prospective gains from a permanent 10% reduction in death rates by major cause of death

	Males	Females	Total
All causes	**20,313,861,359**	**16,732,088,925**	**37,045,950,285**
Infectious and parasitic diseases	115,716,366	99,084,256	214,800,622
Diabetes mellitus	130,030,063	124,821,863	254,851,926
Pneumonia & influenza	896,555,281	1,085,704,943	1,982,260,224
Chronic liver disease and cirrhosis	228,956,475	136,257,429	365,213,904
Chronic obstructive pulmonary disease and allied conditions	624,002,538	492,985,476	1,116,988,014
Malignant neoplasms	3,489,167,761	3,194,545,748	6,683,713,508
Malignant neoplasm of digestive organs and peritoneum digestive organs	1,035,944,984	746,734,911	1,782,679,895
Malignant neoplasm of trachea, bronchus and lung respiratory	903,510,859	547,508,496	1,451,019,356
Malignant neoplasm of female breast	0	644,106,359	644,106,359
Malignant neoplasm of genitourinary organs	568,762,040	487,621,167	1,056,383,207
Major cardiovascular disease	5,595,604,968	4,396,739,344	9,992,344,312
Diseases of the heart	4,691,439,374	3,191,307,798	7,882,747,172
Cerebrovascular disease	828,305,582	1,135,153,553	1,963,459,135
Accidents and adverse effects	553,175,198	244,911,322	798,086,520
Motor vehicle traffic accidents	241,718,343	72,890,129	314,608,472
Homicide and injury purposely inflicted by other persons	22,442,942	11,189,616	33,632,558
Suicides and injury undetermined whether accidentally or purposely inflicted	388,528,585	120,526,517	509,055,102

Notes: Sub-categories are not exclusive and therefore do not total to the figures given in major categories

4. Sensitivity analysis

The general results are of course sensitive to the assumptions made. The basic calculation rests on the value of the discount rate, the change in survival probabilities seen across the various decades analysed, the value of θ assumed, which in turn is dependent on the value of life assumed and the value of lifetime consumption, which itself depends on the proxy values for life cycle earnings. It seems reasonable to take a discount rate of 3.5% as this is historically low and reflects current anticipation of the public sector riskless return. The change in survival probabilities cannot reasonably be changed. It is reasonable to assume the value of lifetime consumption is not subject to alteration. The value of life, however, does vary across markedly across different studies even if only UK studies are reviewed (Viscusi and Alby, 2003). Before noting the sensitivity to changes in the value of life however a rough and ready comparison of the UK and US findings as calculated by Murphy and Topel (op.cite.) is undertaken to set the context.

Assuming the US population to be approximately 3.5 times as large as the UK population, an exchange rate of £1 to $0.54 and that average wages were compatible the crude conversion of the UK findings suggests a figure of approximately $20 trillion as the measure of gain from medical R&D in the UK over the period 19700-2000. This is substantially below the Murphy and Topel estimate of $46 trillion. It might be argued that demographic structure accounts for some of the difference but in fact the UK has had a slightly higher proportion of the elderly and lower proportion of the young in its population than the USA. In other words the higher gains in the US do not reflect substantially different demographics which translate into higher improvements in survival probabilities. There is some evidence to suggest that the US population may be less healthy than the UK population and therefore may have more to gain from R&D investment however (Banks, 2006). In all likelihood then the estimate of the value of life used in the present study (£1.14 million; approximately $0.6 million) compared to the $5 million used by Murphy and Topel explains the difference across the calculations. The value of life provides data necessary to

calculate θ in equation (7) and used in subsequent calculations. In fact when the UK value of life is set at £1.14 million the value of θ is 2.84, as compared to a value of θ of 2.9 calculated by Murphy and Topel when using a value of life set at $5 million. As noted in the introduction the estimates of the value of life gained from the UK vary widely and the estimates based on compensating differentials are "implausibly large" (Viscusi and Abby, 2003). That said if the UK value of life is increased to £2.7 million (approximately $5 million), which is at the higher end of the UK valuations, θ becomes 6.73 and the calculated gain from medical R&D becomes £6.4 trillion ($12.8 trillion), which when multiplied up to the US population scale is a close approximation to the Murphy and Topel estimate ($44.8 trillion). This increase in the value of line is roughly in line with the upper end of UK value in life estimates which are gained when individuals are asked about risk of death in direct relation to specific diseases, most notably heart disease and cancer (Jones-Lee et al, 1985; Andrews and McCrea, 1999). The point being that amongst other factors the results are extremely sensitive to the value of life adopted. The £1.14 million adopted in this study reflects the value currently adopted by UK government.

Of course one must be careful in drawing inferences about the rate of return. First all of the caveats concerning the calculations should be remembered: in particular the inferred gain rests on a number of assumptions relating to the value of life, lifecycle consumption and the conversion of R&D into reductions in survival probability regardless of gains in achieved through changes in life style and environment. It is simply incorrect to attribute the full return of improved UK survival probability merely to UK medical R&D. Importantly, life style changes, environmental changes and any spillover benefits gained from R&D conducted abroad are not taken account off. That said, as noted above there has been no consideration given to improvements in quality of life.

Obviously the annual investment in the UK medical sector is tiny compared to the estimated net gain of £2.58 trillion, albeit that this gain accrued over a 30-year period. The investment is less than 1% of the total monetarised gains estimated above. Moreover this assumes investments have been at this historically high level, which is not the case.

5. Conclusions

This paper has replicated the work of Murphy and Topel in the UK context at a time when increased interest has been focussed on the return to health sector R&D (UK Evaluation Forum, 2006). The results show that even when, in comparison to this earlier work, the value of a statistical life is lowered in absolute terms and lower UK health expenditure growth is netted out of the calculations the return to UK medical R&D can be inferred to be substantial. This conclusion is reached with fairly rudimentary calculations of the monetary return to improved life expectancy. Of course such an inference neglects any impact of lifestyle and environment on life

expectancy during the timeframe considered, but this omission is balanced by focus on mortality to the neglect of monetary estimates of the improvements in quality of life attributable to medical research over the period.

It represents a first attempt to apply the value of life approach to measure the gains to medical research within the UK. Buxton et al (2004) attempt to calculate the return within the UK context in a different manner which does not easily lend itself to aggregation of benefits. That said many conceptual issues remain unresolved with the present methodology. For example the appropriateness of the time period considered, how to deal with the issue of externalities and not least how to truly net out the impact of R&D alone on improvements in life expectancy let alone gains in quality of life. The results suggest that if these narrow money based estimates are correct investment in medical R&D in the UK, while relatively small in absolute terms when compared to the monetarised gains, would have added approximately two years of GDP growth to the UK's economic welfare.

References

Andrews, R.M., and McCrea, P., 1999, "UK Health and safety executive approach to exposure limit setting" in the *Proceedings of the OECD Workshop on the Integration of Socio-Economic Analysis in Chemical Risk Management Decision Making*, London, January 1998, Paris: OECD, pp193-202

Arrow, K., 1962, "Economic welfare and the allocation of resources for innovation", in R.R. Nelson, (ed.) *The Rate and Direction of Innovative Activity*, Princeton, NJ, Princeton University Press.

Banks, J., Marmot, M., Oldfield, Z. and Smith, P., 2006, "Disease and Disadvantage in the United States and in England**",** *Journal of the American Medial Association*, 295: 2037 - 2045.

Buxton, M., Hanney, S., and Jones, T., 2004, "Estimating the economic value to societies of the impact of health research: A critical review", Bulletin of the World Health Organisation, 82, 733-739.

Chilton, S., Covey, J., Hopkins, L et al, 2002, "Public perceptions of risk and preference-based values of safety", *The Journal of Risk and Uncertainty*, 25:3, 211-232

Jones-Lee, M., Hammerton, M. and Phillips, P.,R., 1985, "The value of safety: Results of a national sample survey" *Economic Journal*, 95, 49-72

Mishan, E., 1971, "Economic valuation of life and limb: A theoretical approach" J*ournal of Political Economy*, 79:4, 687-705

Murphy,K.M., and Topel R.H., 2001, "The Economic Value of Medical Research", in Murphy,K.M., and Topel R.H., (eds.) *Measuring the Gains from Medical Research: An Economic Approach*, Chicago, Chicago University Press

Nord, E., 1992, "The person trade-off approach to valuing health care programs", *Medical Decision Making*, 15:3, 201-208

Office of National Statistics (ONS), 2004, *Individual Income 1996/7-2003/4* in conjunction with the DTI Women and Equality Unit. London, HMSO.

Stoneman, P., 2001, "Government spending on Research and Development in the UK", in Miles, D., Myles, G. and Preston, I. (eds) *The Economics of Public Spending*, Oxford, OUP

UK Evaluation Forum, 2006, *Medical Research: Assessing the Benefits to Society*, London, Academy of Sciences, the MRC and the Wellcome Trust.

Viscusi, K. W., and Aldy, J.E., 2003, "The value of a statistical life: A critical review of market estimates throughout the world", *The Journal of Risk and Uncertainty*, 27:1, 5-76