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Abstract

Societal preferences related to risk acceptance form an important input into decisions affecting the selection and deployment of large-scale technological systems. These preferences may be determined either by psychometric survey techniques or through the analysis of recorded statistical data. The latter method, revealed preferences, has been used, most notably by Starr, to derive mathematical relationships between societal benefit and technological risk. In this paper the merits of the revealed preference approach are summarized and the validity of the Starr quantitative results is examined. It is concluded that these results are excessively sensitive to the assumptions made and the handling of data and that the existence of simple mathematical relationships, based upon the revealed preferences method, is unlikely. Plans for further research in determining societal preferences are outlined.

I. INTRODUCTION

As technological systems have increased in size they have offered increasingly attractive societal benefits. However, with this increase in scale the negative side-effects of technology have also become more noticeable - as reflected in the environmental concerns of recent years. Plans for further progress are often being met by a variety of individual and group demands for closer examination of the benefits and risks of technologies; attitudes which regard much that is innovative as being potentially harmful are being observed.

Thus decisions involving the selection and deployment of large-scale technologies have taken on an increased importance,

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with societal attitudes and anticipated responses forming a vital input into decision making. A model illustrating the importance of risk perception and societal preferences in this process has been reported in an earlier publication (Otway, 1975).

There are basically two methods for determining preferences on the societal level: psychometric survey techniques; and the revealed preferences approach, which relies upon the analysis of recorded statistical data. The latter method tries to extract from historical data preferences revealed, explicitly or implicitly, in past societal-level decisions and attempts to describe a normative pattern for these decisions.

One of the better known applications of the revealed preferences approach, as related to technological risks, is that of Starr (1969, 1971, 1974) who, through this pioneering work, was instrumental in stimulating interest in the general field of applied risk-benefit analysis and in opening new lines of enquiry. The objective of the Starr work was to establish a set of hypotheses and criteria which could be used for national decisions regarding the acceptable level of risk associated with large-scale technological systems. Historical patterns (revealed preferences) were sought which might suggest broad principles for this purpose and several basic mathematical relationships between social benefit and technological risks were suggested - with some qualifications as to their validity and the limitations of the method. These papers have been frequently cited, often with insufficient qualification, with the quantitative relationships sometimes appearing to be regarded as a set of "quasi-laws" describing human behaviour in risk situations.

One of our early research tasks was to critically review methods for the determination of societal preferences. In light of the inherent limitations found in the method of revealed preferences we were struck by the rather neat mathematical results obtained by Starr through this approach. This, in turn, leads to a more detailed examination of the quantitative correlations themselves. The intent of this paper is to summarize some limitations of the revealed preferences approach (Section II), to outline the results and methodology of the Starr work (Section III), and, in Section IV, to review basic premises and to attempt reproduction of the results. Conclusions are presented in Section V.

II. REVEALED PREFERENCES - GENERAL COMMENTS

This approach has the obvious advantage of dealing with actual societal decisions which have been made, explicitly or implicitly, in the real world and is free from the artificialities of the laboratory. However, the application of this method re-

quires that several assumptions be made which lead to the disadvantages summarized below:

1. Past is Prologue. This is the core of the assumption that societal attitudes revealed in the past can be applied in the future. While this may be true in some cases, especially for short time periods, society is changing rapidly - precisely because of technological development. This assumption is open to question.

2. Multiple Determination. Preferences related to risk acceptance are multiply determined; that is, many factors influence attitudes toward risk. It is not clear that all are even known, let alone recorded in the data base.

   For example, individual and societal acceptance of risk is, in general, predicated upon how risks are perceived, not by actual risk levels; it is known that man is a poor intuitive statistician in this respect (Slovic, 1971; Murphey and Winkler, 1973). Recorded statistical data reveal actual levels of risk; how risks and benefits were perceived at the time cannot be reflected in these data, nor can the socio-psychological mechanisms that determined perception be recorded.

   Raiffa (1968) has pointed out the importance of information quality. People have made the decisions which generated the recorded data on the basis of imperfect information. Decisions made in the future, even if all other conditions were constant, may be made with better or worse information and, therefore, will not necessarily reproduce past outcomes.

3. Importance of Physical Risks. More specific to the Starr work, which emphasizes physical (especially mortality) risks, is the observation that these risks do not always play a dominant rôle in the acceptance of a new technology. Risks are often taken for social reasons, such as prestige, etc., and in the search for psychic benefits thoughts of physical risk may be subordinate to, for example, social risks.

These points summarize the principal arguments against using the revealed preferences approach for determining valid societal preferences related to risk acceptance. However, as mentioned earlier, Starr has postulated some basic mathematical relationships between societal benefit and technological risk using this method; his work will be summarized in the next section.

III. SUMMARY OF THE STARR WORK

In this section the important points of the Starr conclusions will be repeated and the methods used in their derivation reviewed. This treatment is necessarily brief - readers are encouraged to study one of the original papers (Starr, 1969, 1971, 1974) for a more complete exposition. The 1969 paper will be used for this discussion as it formed the basis for the later work and the results were not changed appreciably.

A. The Assumptions

The Starr work presents "an approach for establishing a quantitative measure of benefit relative to cost for an important element in our spectrum of social values - specifically, for accidental deaths arising from technological developments in public use. The analysis is based upon two assumptions:"

1. "..... that historical national accident records are adequate for revealing consistent patterns of fatalities in the public use of technology."

2. "..... that such historically revealed social preferences and costs are sufficiently enduring to permit their use for predictive purposes."

The above quotes are from the 1969 paper and were paraphrased in the 1971 and 1974 papers.

B. The 1969 "Conclusions"*

"(i) The indications are that the public is willing to accept 'voluntary' risks roughly 1000 times greater that 'involuntary' risks.

(ii) The statistical risk of death from disease appears to be a psychological yardstick for establishing the level of acceptability of other risks.

(iii) The acceptability of risk appears to be crudely proportional to the third power of the benefits (real or imagined) ....."

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* Starr did not use the word conclusions in direct association with these relationships. In the 1969 paper they appeared in a section headed "Conclusions" and in all three publications were referred to as "interesting points".

These three points were repeated, in a somewhat different form, in the 1971 and 1974 papers. Further points addressing the factors influencing public awareness, the acceptability of nuclear power and the significance of natural hazard risks levels in acceptance will not be discussed here.

C. The Methodology and Results

The intent here is to briefly follow through the methodology and data presentations used in reaching the points listed above. The figures are presented in the same order followed by Starr.

1. Risk proportional to $(\text{benefit})^3$.

   There are two basic sources for this result: mining wages and societal activities. It was noted that accident rates for miners, exposed to high occupational risks, were a function of the wage, roughly the third power relationship shown in Figure 1.

   Risks and benefits were then estimated for several voluntary and involuntary societal activities (Figure 2) and the third-power relationship between benefit and risk characteristics was again said to be observed.

2. Acceptability of voluntary risks ~ 1000 times that of involuntary risks.

   The curves of Figure 2 for voluntary and involuntary risks show an approximate separation of three orders of magnitude, thus providing the basis for this point.

3. The statistical risk of death from disease as a psychological yardstick for acceptability.

   Several figures were presented (such as Figure 3) which illustrated that participation in activities (e.g., automotive travel, commercial aviation) increased as the associated risks decreased. Discussing Figure 3 it was said: "It is interesting to note that the present risk level is only slightly below the basic level of risk from disease. In view of the high percentage of the population involved, this probably represents a true societal judgement on the acceptability of risk related to benefit" (Starr, 1969, 1971, 1974).

IV. EVALUATION AND REPRODUCEABILITY OF THE STARR RESULTS

This section will examine the validity of the foregoing application of the revealed preferences technique by repeating the analysis

outlined in Section III. C., using the same data base. No changes in methodology or calculation will be made.

1. Risk proportional to (benefit)^3

a. Mining Wages

Figure 1 indicated a cubic relationship between miners' wages and occupational risks. Otway (1973) pointed out that the total wage should not be viewed as risk compensation; workers exposed to minimal occupational risk still receive a wage for basic services. A review of wage scales for bituminous coal mining indicates that an average compensation for basic services in 1967 was about $ 2.00 per hour (U.S. Dept. of Labor, 1967). References in wage and salary administration (Otis and Leukart, 1954; National Metal Trades, 1974) indicate that, in establishing industrial wage scales, job hazard accounts at most for 10 % of total wages. Subtracting $ 2.00 per hour from the wages of Figure 1 to form "risk compensation" wages, indicates an essentially linear relationship between risk and benefit. Figure 4 shows a comparison between risk compensation wage and the total wage data of Figure 1 with regression lines.

A further review of mining wage data (U.S. Dept. of Labor, 1967) indicates that wages in larger coal mines were generally higher than in smaller mines, although the smaller mines had higher accident rates. This also implies the effect of variables other than risk upon wages.

Connoly and Mazur (1971), using the Starr aggregate wage approach, included data from other mining industries and various States of the USA. With these additional data points they concluded that the "inference of a general third-power relationship, or any relationship, does not appear to be justified".

b. Societal Activities (Voluntary)

Having gained the impression from the foregoing that a third-power relationship between benefit and risk does not necessarily exist, the third-power relationship shown in Figure 2 may be investigated. The original voluntary risk data, taken directly from Figure 2, are fitted best to a regression equation indicating risk to be proportional to benefit to the 1.8 power. (The original Starr data and the regression line are shown in Figure 5.)

c. Societal Activities (Involuntary)

The "involuntary" curve of Figure 2 consists of four data points: motor vehicles, commercial aviation, electric power and natural hazards (Starr, 1975). The appendices of the

Starr papers indicate that no benefit was assigned to the natural hazards point, therefore, it was arbitrarily placed along the benefit axis.

Disregarding natural hazards, a regression line may be fitted to the remaining original data. This yields an equation of the form $R B^{6.3}$ - a sixth power relationship for involuntary risks. (See Figure 5).

2. Acceptability of voluntary risks ~ 1000 times that of involuntary risks.

Although it appears that an element of personal control over outcome and the possibility of avoiding risk exposure (i.e., voluntary risk taking) play an important part in risk acceptance, any numerical relationship between voluntary and involuntary risk acceptance, based upon the Starr data (shown with fitted curves in Figure 5), where the relationships for voluntary and involuntary activities intersect, would seem speculative.

3. The statistical risk of death from disease as a psychological yardstick for acceptability.

As discussed earlier (Section III. C. 3) curves such as Figure 3 were used to show that participation in many activities increased as risks decreased with "a true societal judgement on the acceptability of risk in relation to benefit" being reached as participation became virtually universal and risk levelled at a value near that to death from natural causes.

While this may be true, although the mechanism is not obvious, curves such as Figure 3 do not demonstrate a cause-effect relationship between participation and risk. Starr did not claim that cause-effect had been shown but this impression could be obtained from the figures. Participation in risk-bearing activities is multiply determined; other variables besides risk levels, e.g., economic, may also influence participation. This century has been a time of great social change in the U.S.A., a period of industrialization and increasing personal wealth. Figure 6 shows, for example, a plot of disposable personal income and participation in automotive travel vs. time. It may be observed that in the period when automotive participation increased by a factor of 7 or so, personal disposable income, in constant dollars, increased by a factor of about 4. It is not unreasonable to hypothesize that as incomes increased the automobile was economically within the reach of more people, thus increasing participation. The point here is not to postulate an alternative cause-effect relationship but to suggest that any hypothesis about participation in such activities being strongly influenced by risk levels approaching that from natural causes should not be regarded as conclusive.

4. General Remarks.

The number of statistical variables recorded is limited and it is, therefore, necessary to make a number of assumptions in performing such analyses. Using equally reasonable, but different, assumptions could produce quite different results - especially with regard to Figure 2. This has not been done here; the original data for voluntary and involuntary activities have merely been fitted to computer-determined power curves in order to objectively test the appropriateness of the quantitative correlations.

The reader may wish to examine some of these original data points in detail in order to get an idea of the uncertainties introduced through some of the assumptions necessary to compensate for inadequacies in the data base. For example, the Starr method for determining the societal benefit of electrical power is based upon the possible change in per capita GNP if electricity were not available. In view of the correlation between energy consumption and GNP, and the assumption that 35 % of the energy consumed in the USA is used to produce electricity, Starr assigned a per capita benefit of about $ 1,000 to electric power (almost 25 % of the U.S. per capita GNP). An alternative value may be suggested through a somewhat different approach: The U.S. Statistical Abstracts (1973) indicate that the U.S. gross product for "Electricity, Gas and Sanitary Services" is $ 25,000 million. Even if this were all attributed to electricity the per capita benefit would be only about $ 100. This is not to imply that one number or method is correct and the other incorrect - only to show that different assumptions can produce rather large changes in the location of data points.

Finally, it must be observed that the data of Figures 2 and 5 do not really justify the use of computer-fitted curves which, due to the limited number of data points, are extremely sensitive to a change in location of a single point. Regression analyses were used solely to obtain an impartial test of the cubic relationships which had been postulated. It seems difficult to obtain adequate information on a significantly large number of societal activities to allow broad generalizations of the type sought by Starr. This appears to be another limitation of the method.

V. CONCLUSIONS

It must again be emphasized that the intent of this paper was not to question the value of the Starr work in general, but merely to test the validity of quantified risk-benefit correlations based upon the method of revealed preferences. Starr himself did not place a great deal of stress upon the validity of the relationships themselves - as may be seen by the caveats he quite properly placed in his papers. Our concern was that, due to encouragement given by the elegant simplicity of the mathematical results, too much reliance is being placed on historical statistical data alone as a source of revealed societal preferences.

It is concluded that the results of this method appear to be excessively sensitive to the assumptions made and the handling of data; the present existence of any such mathematical risk-benefit relationships, based upon this approach, would seem unlikely.

There is clearly some relationship between the benefit perceived to be derived from an activity and the perceived costs of participation. The relationships are, however, not simple mathematical ones but complicated and strongly influenced by socio-psychological mechanisms which are as yet not well understood. The research programme of the Joint IAEA/IIASA Research Project includes the expansion of the revealed preferences approach using an iterative process of empirical, multi-variable analysis combined with behavioural theories. These analyses will also help to define inputs to a parallel effort in the design and application of psychometric surveys. This research has been described in an earlier publication (Otway, 1975) and is directed at identifying the factors influencing the perception and acceptance of technological risks in order that societal attitudes and anticipated responses may be better integrated into decision making.

Acknowledgement

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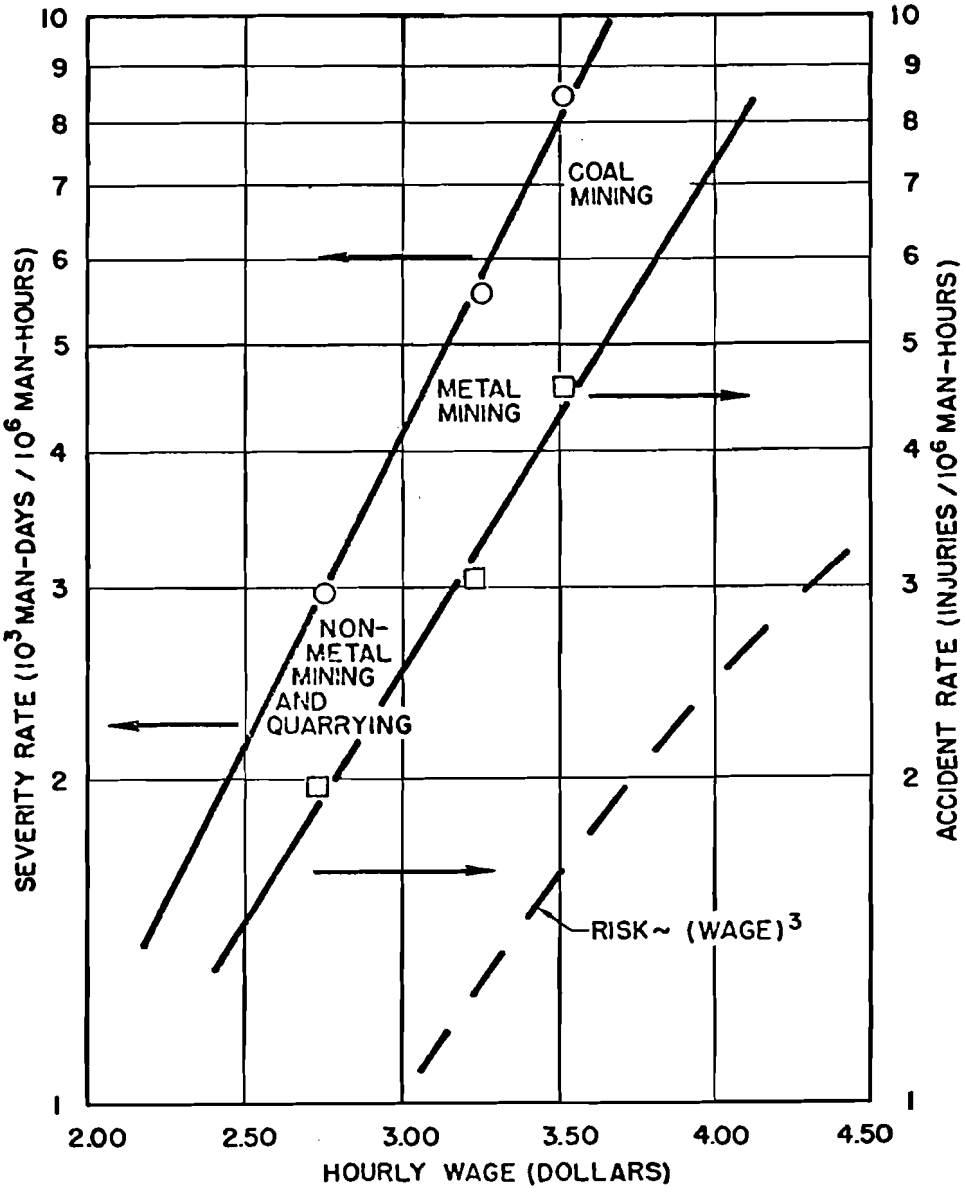

FIGURE 1

Mining Accident Rates vs. Incentive (Starr 1969, 1971, 1974)

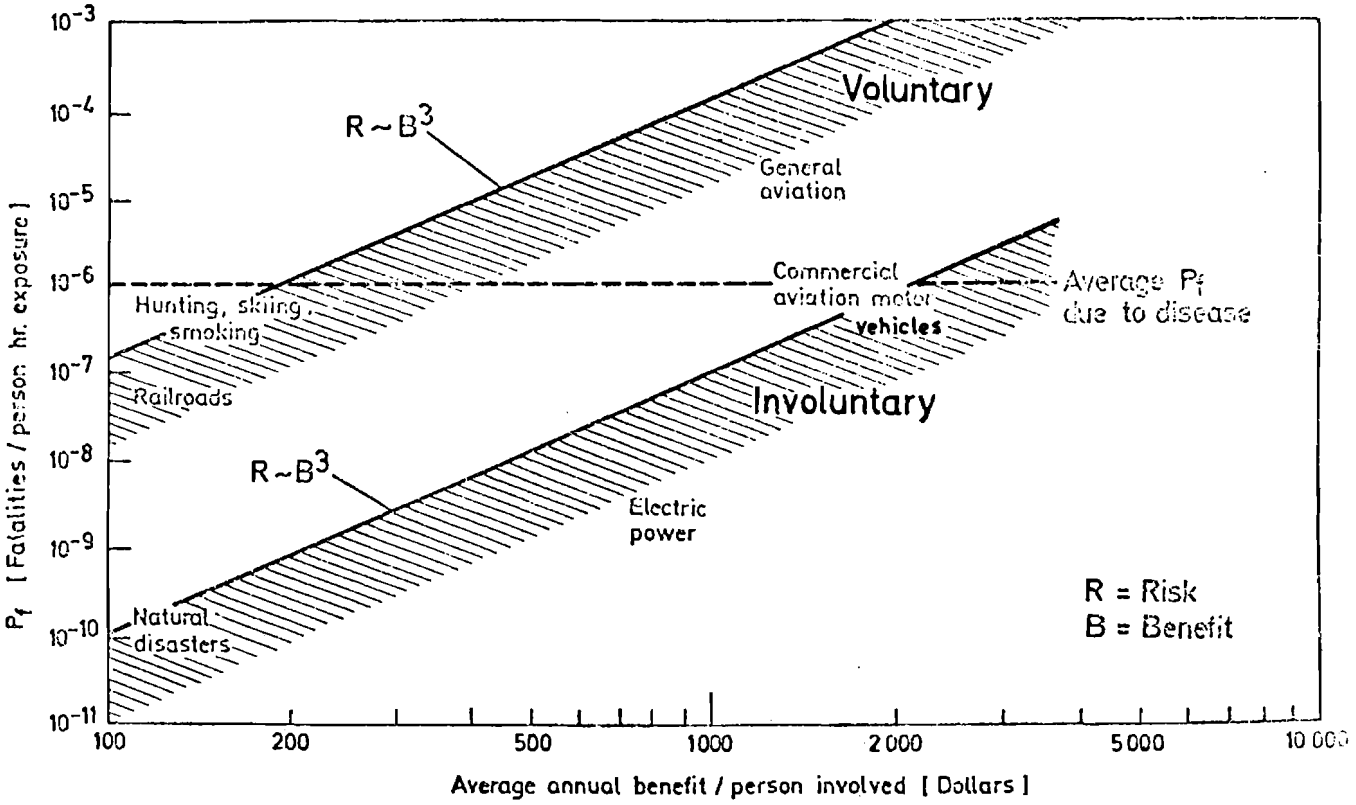

FIGURE 2

Risk vs. Benefit: Voluntary and Involuntary Exposure (Starr 1969, 1971, 1974).

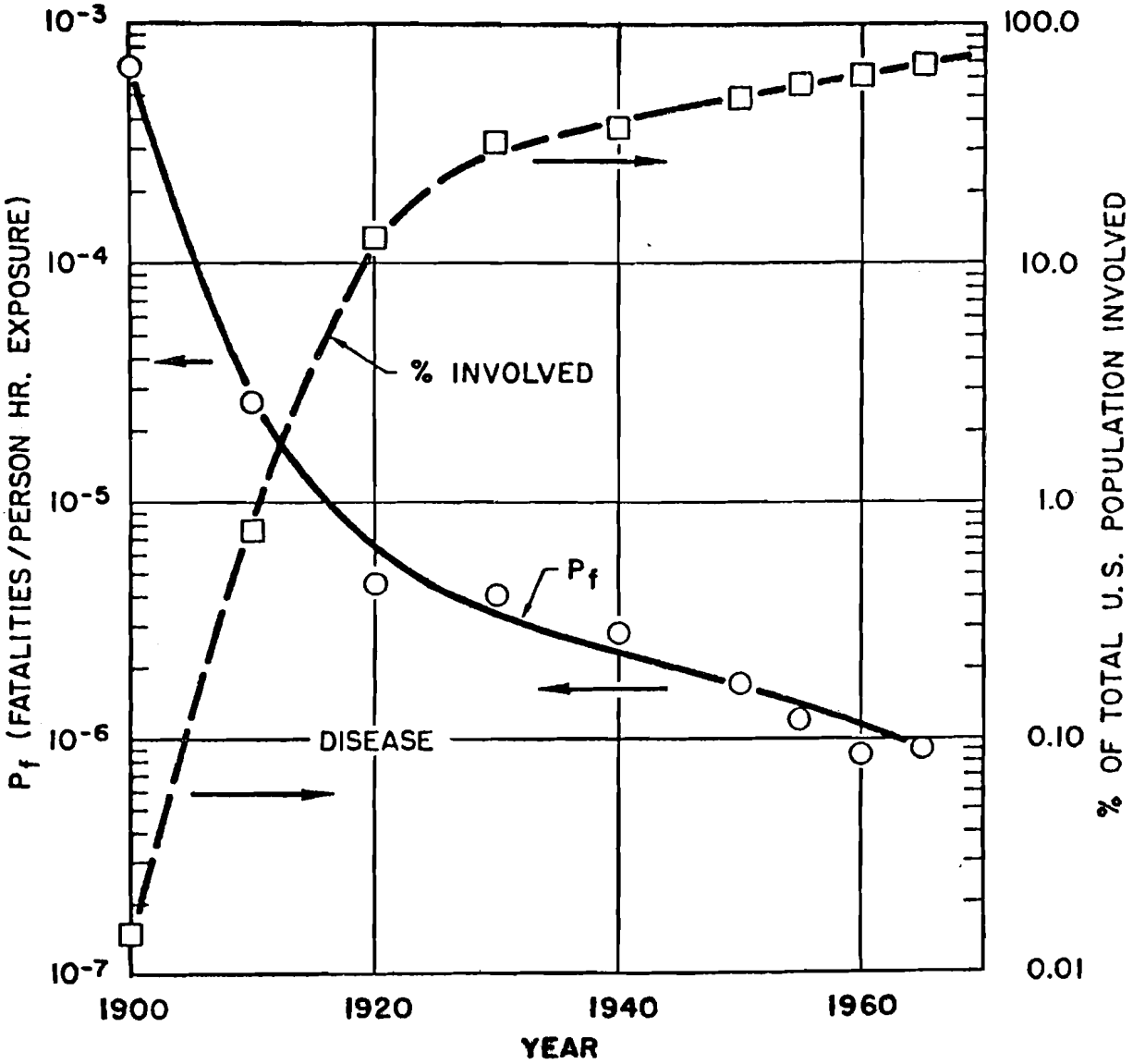

FIGURE 3

Risk and Participation Trends for Motor Vehicles (Starr 1969, 1971, 1974).

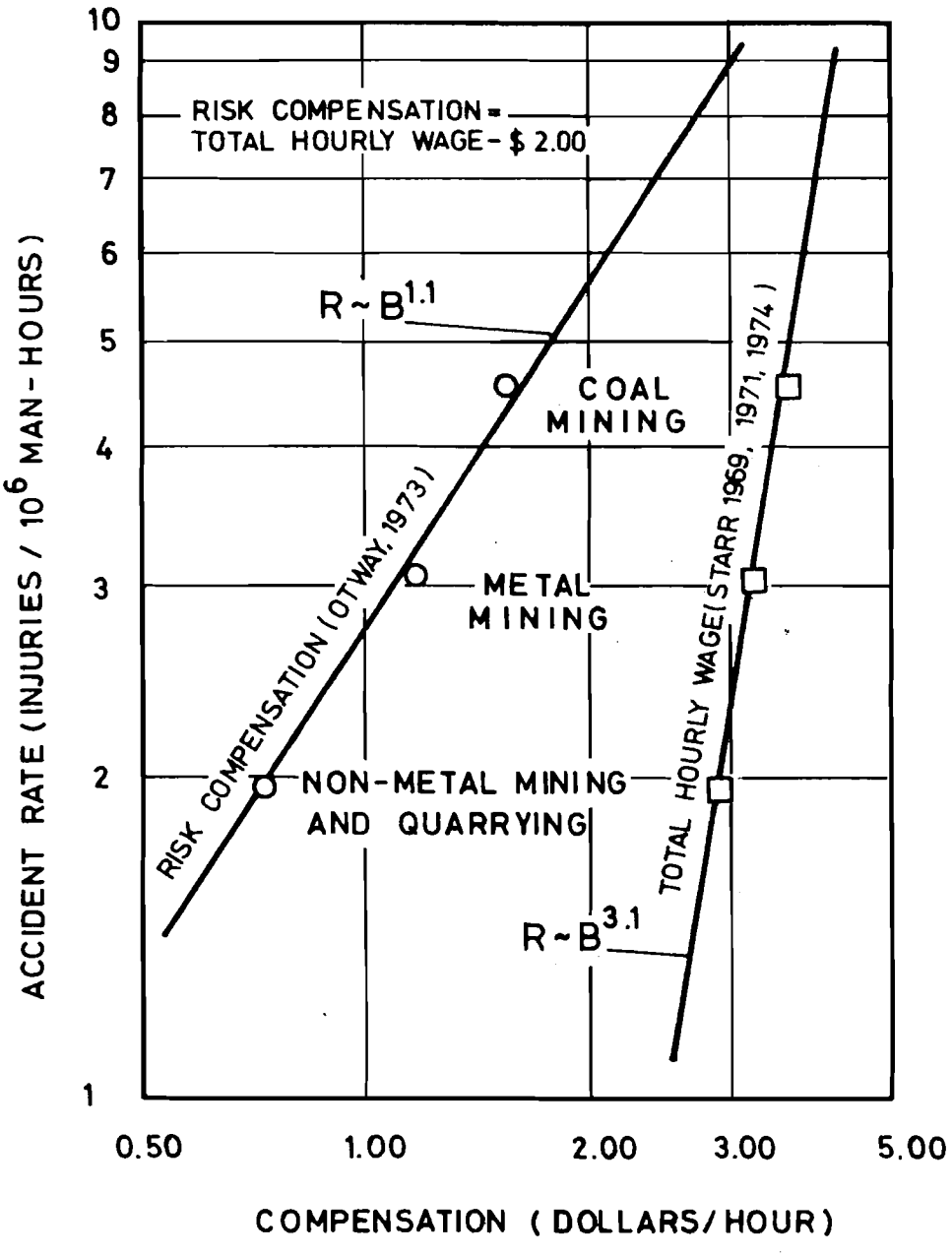

FIGURE 4

Mining Accident Rates vs. Total Wage and Risk Compensation

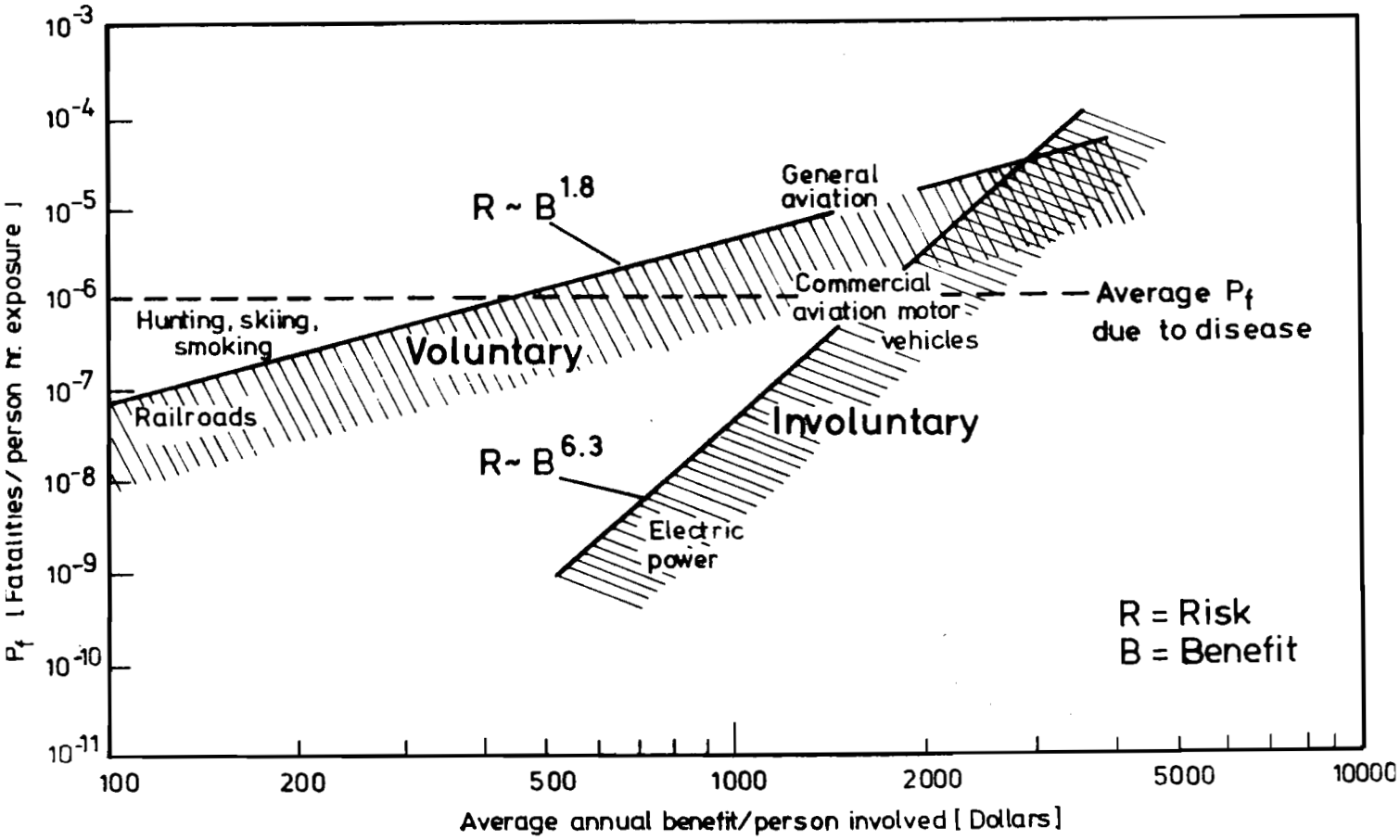

FIGURE 5

Risk vs. Benefit : Regression Lines for Voluntary and Involuntary Exposure (original Starr data)

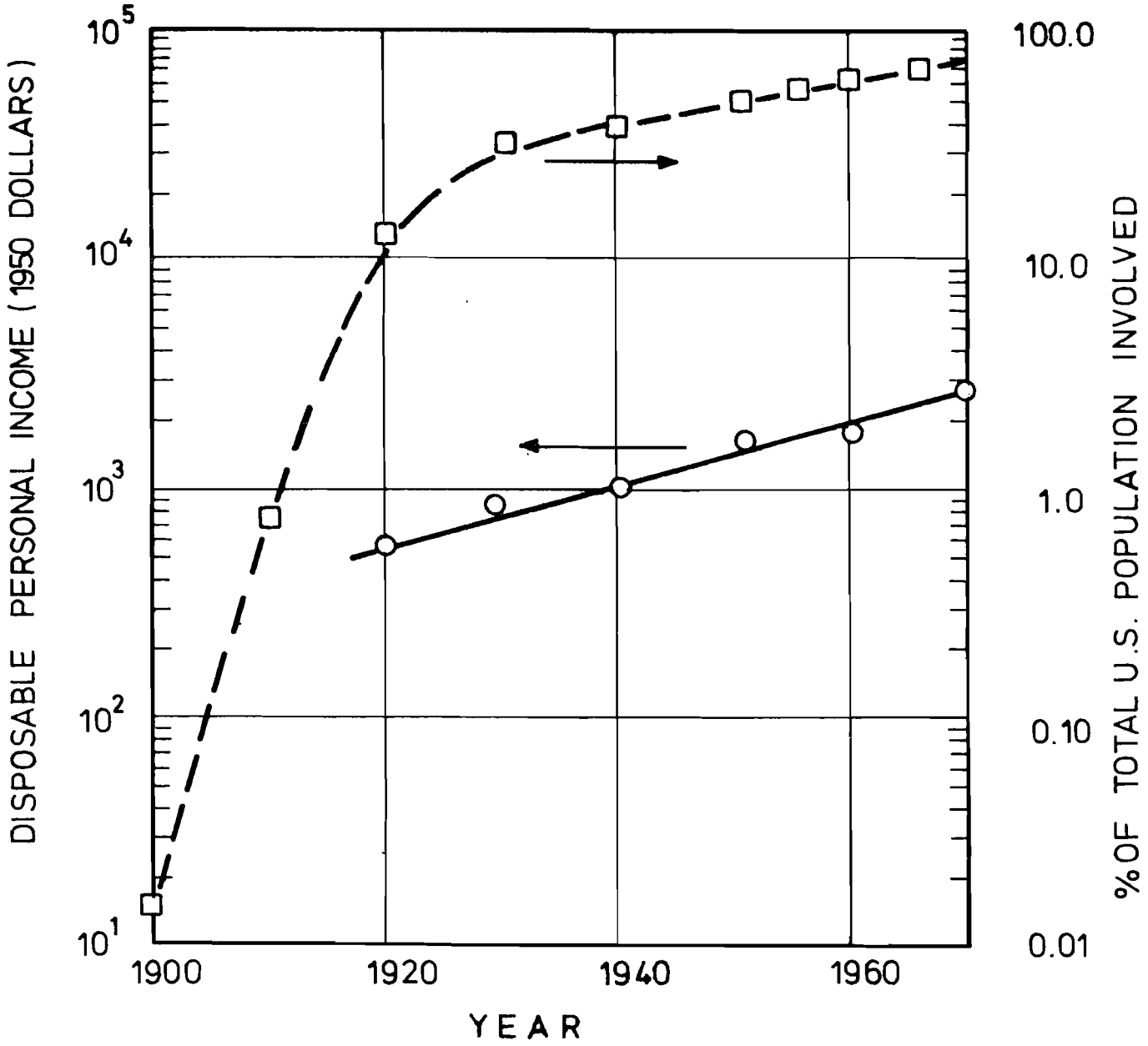

FIGURE 6

Disposable Personal Income and Participation Trends for Motor Vehicles.

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