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Economic development and traffic accident mortality in the industrialized world, 1962–1990

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Background	We examined the association between prosperity and traffic accident mortality in the industrialized world in a long-term perspective.
Methods	We calculated traffic accident mortality, traffic mobility and the fatal injury rate of 21 industrialized countries from 1962 until 1990. We used mortality and population data of the World Health Organization (WHO), and figures on motor vehicle ownership of the International Road Federation (IRF). We examined cross-sectional and longitudinal associations of these traffic-related variables with the prosperity level per country, derived from data of the Organization for Economic Cooperation and Development (OECD).
Results	We found a reversal from a positive relation between prosperity and traffic accident mortality in the 1960s to a negative association currently. At a certain level of prosperity, the growth rate of traffic mobility decelerates and the fatal injury rate continues to decline at a similar rate to earlier phases.
Conclusions	In a long-term perspective, the relation between prosperity and traffic accident mortality appears to be non-linear: economic development first leads to a growing number of traffic-related deaths, but later becomes protective. Prosperity growth is not only associated with growing numbers of motor vehicles in the population, but also seems to stimulate adaptation mechanisms, such as improvements in the traffic infrastructure and trauma care.

Keywords	Traffic accident mortality, traffic mobility, fatal injury rate, economic development
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Economic development is one of the main determinants of changing patterns of mortality and disease.[1,2] Rising living standards in a population make a major contribution to the transition from a cause-of-death-pattern dominated by infectious diseases with very high mortality to a pattern dominated by chronic diseases with lower mortality.[3] Over the last century, this 'epidemiologic transition'[4,5] has been completed in all the countries of the industrialized world, whereas in developing countries it is still underway.[6] General evidence shows that economic growth is associated with improvements in the health of populations.[7–9]

Economic growth, however, sometimes leads to a deterioration in the health of a population. In the industrialized world, for example, the post-World War II period (1945–1970) was not only characterized by the most favourable economic development of the past century, but also by a rapid increase of cardiovascular diseases and traffic accidents.[10–12] Because of these developments the concept of 'diseases of affluence' or 'western diseases' was introduced,[13,14] pointing to growing prosperity as a possible determinant of specific disorders.

More recent findings have shown the weaknesses in this concept. In the 'western' world the rising trends in cardiovascular mortality of the 1950s and 1960s were later reversed in spite of growing prosperity.[15] In the former socialist economies, on the other hand, cardiovascular mortality surged upwards in the face of the poor economic development in this part of the world.[16] Currently, in the industrialized world, the lowest levels of cardiovascular mortality are found in the most prosperous regions.[17,18]

Traffic accidents are another cause of mortality and morbidity, where the concept of 'diseases of affluence' needs further clarification. In order to examine this relation, several cross-sectional studies have been performed so far. These have produced results that were more or less contradictory. It has been found that on the scale of the whole world, the gross national product per

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capita shows a positive correlation with the number of traffic deaths in the population (traffic accident mortality). Adjustment for variation in the number of motor vehicles in the population (traffic mobility), however, leads to different findings. There is a strong negative association between prosperity and the number of traffic deaths per motor vehicle (fatal injury rate).[19] On a global scale, therefore, prosperity appears to be a determinant of traffic accident mortality with the number of motor vehicles as a major intermediate factor. A positive association between prosperity and traffic accident mortality has also been found in cross-sectional studies focusing on low-income and middle-income countries.[20] However, studies restricted to high-income countries have produced different findings. Analyses into regional variation in traffic accident mortality in high-income countries have consistently shown the lowest mortality levels in the most affluent regions.[21–24] These findings show that, from cross-sectional studies, no uniform relation between prosperity and traffic accident mortality can be derived. Perhaps the key to understanding can be found in a long-term perspective. The cross-sectional associations between economic factors and traffic accident mortality in high-income countries may well have changed over time, similar to observations made in the field of cardiovascular diseases.[17,18]

To date hardly any attention has been paid to the role of traffic accidents in the changing mortality patterns over the last century (i.e. the epidemiologic transition) and their explanations. Therefore, it could be worthwhile to examine the relationship between prosperity and traffic accident mortality and its underlying parameters (i.e. traffic mobility and fatal injury rate) in a long-term perspective, using data from several decades.

This article reports the results of an analysis of developments in traffic accident mortality in 21 industrialized countries between 1962 and 1990, addressing the following questions: (1) How have the cross-sectional associations between prosperity and traffic accident mortality been developing since the early 1960s, and what has been the influence of traffic mobility and the fatal injury rate on those associations? (2) What is the general shape of the longitudinal relationship between prosperity and traffic accident mortality, and how can it be explained in terms of developments in traffic mobility and the fatal injury rate?

Data and Methods

Our analysis used data from the member countries of the Organization for Economic Cooperation and Development (OECD). These countries are referred to as the 'industrialized world'[19] or the 'established market economies'.[25] We were able to collect data from the 21 OECD countries with a population size of more than one million inhabitants for each year from 1962 until 1990.

Data were acquired on traffic accident mortality (the number of traffic deaths per 1000 person-years), traffic mobility (the number of motor vehicles per 1000 person-years), and the fatal injury rate (the number of traffic deaths per motor vehicle in the population).

Traffic accident mortality

The figures on traffic accident mortality were obtained in the following way. The number of traffic deaths by age (0–4, 5–14, …, 65–74, 75+), sex, year (1962–1990) and country of residence was available from a computer file on mortality from external causes-of-death supplied by the World Health Organization (WHO). From this file the following codes were selected: AE 138 (motor vehicle accidents) and AE 139 (other transport accidents) according to the basic tabulation list of ICD-6, -7 and -8; E471 (motor vehicle accidents) and E470, 472–474, 479 (other transport accidents) according to the basic tabulation list of ICD-9. Traffic accident mortality figures could be calculated for individual countries and separate years. We used population numbers broken down according to age, sex, year, and country of residence, which were also supplied by the WHO. The figures were adjusted for differences in the composition of the population (by country and time period) with the help of direct standardization, using the European Standard Population of 1976.[26]

Traffic mobility

The data on traffic mobility were extracted from annual publications of the International Road Federation (IRF).[27] These publications included information on several measures of traffic mobility: the number of passenger kilometres, the number of vehicle kilometres, and the number of motor vehicles in the population. Only with the help of the latter measure (motor vehicle ownership) we were able to construct complete time series in all 21 OECD countries from 1962 onwards. The data on the other measures were incomplete, in particular for the earlier years of the period under review. Therefore, in the analyses reported in this paper we used motor vehicle ownership as a proxy of traffic mobility.

Fatal injury rate

Subsequently, an index of the fatal injury rate by year and country was calculated by dividing the traffic accident mortality figures by the corresponding data on motor vehicle ownership.

In order to study the association between traffic accident mortality and prosperity we used economic data supplied by the OECD. As an indicator of the prosperity levels of countries we calculated Purchasing Power of Currencies (PPC)-estimates of the gross domestic product per capita. This is a measure of the national income per capita, adjusted for differences in purchasing power between national currencies and between time periods. It was specifically developed in order to allow cross-national comparisons of prosperity differences, and is expressed as 'international' dollars.[28]

We calculated the levels of traffic accident mortality, traffic mobility, fatal injury rate and prosperity of the 21 individual OECD countries for each year between 1962 and 1990.

For each separate year the cross-sectional relation between the level of prosperity on the one hand, and the traffic accident mortality, traffic mobility and fatal injury rate on the other, was modelled using linear regression analysis. The variables included were right-skewed and were thus log-transformed before insertion into the models. In addition, the longitudinal relationship between prosperity and the three traffic-related variables was examined by fitting regression models using the pooled data from all 21 countries during the whole period under review. Cubic regression models produced an adequate fit, significantly better than lower order models. This was due to the fact that the data were best described by an asymmetric curve. Interaction terms between prosperity and country were examined, indicating the existence of a sizeable variation among

Table 1 Slope parameters from linear regressions of traffic accident mortality (deaths/1000 person-years), traffic mobility (motor vehicles/1000 person-years) and fatal injury rate (deaths/motor vehicle) on the level of prosperity in cross-sectional data of separate years between 1962 and 1990

Prosperity (international dollars per capita) on	1962	1965	1970	1975	1980	1985	1990
Traffic accident mortality (deaths/1000 person-years)	+0.58**	+0.56**	+0.45*	–0.05	–0.05	–0.30	–0.53*
Traffic mobility (motor vehicles/1000 person years)	+2.16**	+2.06**	+1.94**	+1.63**	+1.28**	+1.11**	+1.06**
Fatal injury rate (deaths/motor vehicle)	–1.50**	–1.50**	–1.49**	–1.68**	–1.32**	–1.42**	–1.59**

* $P < 0.05$, ** $P < 0.01$.

countries. Therefore, the longitudinal relationship between prosperity and the three traffic-related variables was also established for 21 countries separately. This helped to identify specific countries with developments deviating from the general picture.

Results

Table 1 shows that the cross-sectional relation between prosperity and traffic accident mortality has changed in the industrialized world since the early 1960s. There is currently a negative association, which originated in the second half of the 1970s. At that time a reversal from a positive association occurred. During the whole period under review, there was a positive association between prosperity and traffic mobility. Nevertheless, this relation changed in the sense that the slope of the regression line has levelled off. The association between prosperity and the fatal injury rate, on the other hand, was negative and more or less stable over time.

The reversal of the relation between prosperity and traffic accident mortality seems to be based on the observed change in the association between prosperity and mobility.

This is also demonstrated in Figure 1. It is shown that in the 1960s, when prosperity levels were still relatively low in all industrialized countries, a positive cross-sectional association existed between prosperity and traffic accident mortality (Figure 1a). This was based on large rises in motor vehicle ownership with increasing wealth at a low range of prosperity levels (Figure 1b).

In the 1990s, at high prosperity levels in all industrialized countries, an inverse cross-sectional association is found (Figure 1a). Compared to the 1960s the growth of motor vehicle ownership with increasing wealth has become small at this high range of prosperity levels (Figure 1b).

It is illustrated that the strength of the inverse association between prosperity and the fatal injury rate remained more or less unchanged at all levels of prosperity (Figure 1c).

The longitudinal relation between prosperity and the three traffic-related variables is shown in Figure 2. It appears that, when the pooled data of all 21 countries during the whole period under review are used, a cubic regression model can be fitted that includes a reversal at a prosperity level of around 3000 international dollars per capita. Above this level prosperity becomes protective against traffic accident mortality. Figures 2b and 2c show that this is due to the fact that the mobility growth levels off, while the fatal injury rate continues to decline at the same rate as in an earlier phase of economic development.

The models shown in Figure 2 were applicable to the majority of countries included in this analysis. The relation between prosperity and traffic accident mortality showed a reversal in 19 of the 21 countries. In 16 of these countries the reversal took place at a prosperity level of between 2400 and 3600 international dollars per capita. Nevertheless, when testing interaction a significant influence of the country involved was found.

We identified several countries with trends deviating from the general picture. There are two countries in which no reversal was found, despite having achieved prosperity levels in excess of 3000 international dollars per capita: Greece and Spain. Figure 3 shows that the background mechanisms of this observation are rather different for those two countries. In Greece, the growth rate of motor vehicle ownership has not levelled off so far. In this country (i.e. the poorest country of the analysis) growing prosperity is still resulting in an increasing number of traffic deaths because of rapidly growing numbers of motor vehicles in the population. In Spain, on the other hand, the decline in the fatal injury rate levelled off after reaching the point where prosperity is expected to become protective. However, in both Greece and Spain the fatal injury rate is still relatively high in comparison to most other countries within the industrialized world.

There are a few countries (USA, Japan, Denmark, Finland) for which the models have indicated that the decline in traffic accident mortality ceased after passing a prosperity level of around 14 000 international dollars per capita, because the decline in the fatal injury rate has gradually levelled off. For the USA and Japan this is demonstrated in Figure 4.

Discussion

In the industrialized world, prosperity has become protective against traffic accident mortality since the second half of the 1970s, whereas it led to rising numbers of traffic deaths in earlier years. At low prosperity levels, increasing wealth gave rise to rapidly growing numbers of motor vehicles in the population. Mobility growth, however, has the tendency to level off after reaching a certain level of prosperity. At that point, increasing prosperity becomes protective against traffic accident mortality because it is accompanied by a declining number of traffic deaths per motor vehicle or 'fatal injury rate'. This could be an indirect effect of growing prosperity, which might facilitate several adaptations, including improvement in the traffic infrastructure and medical care for injury victims.[12] Adaptations stimulated by growing prosperity have in the literature been referred to as 'assets for health', leading to general improvements in the health of the population.[9]

Our results indicate that prosperity is an important factor behind developments in traffic accident mortality. In a long-

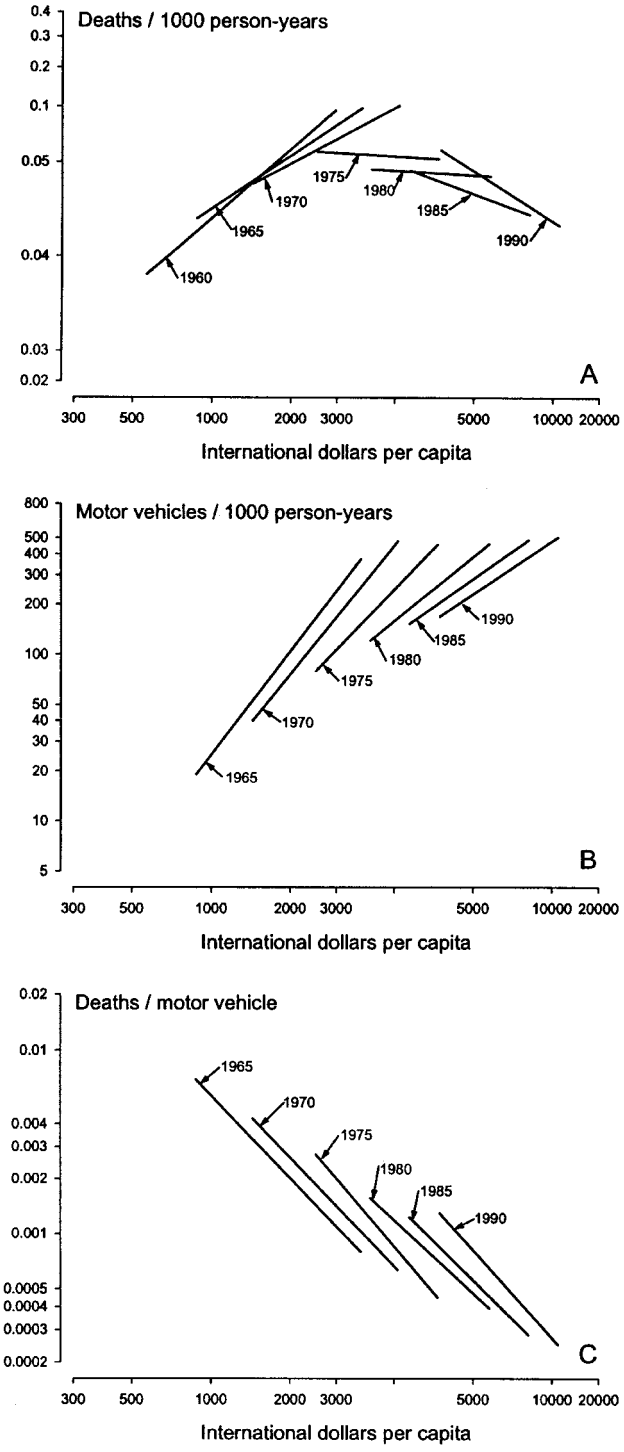

Figure 1 The relationship between traffic accident mortality (deaths/1000 person-years), traffic mobility (motor vehicles/1000 person-years) and the fatal injury rate (deaths/motor vehicles) with the level of prosperity (international dollars per capita) in 21 OECD countries, 1962–1990

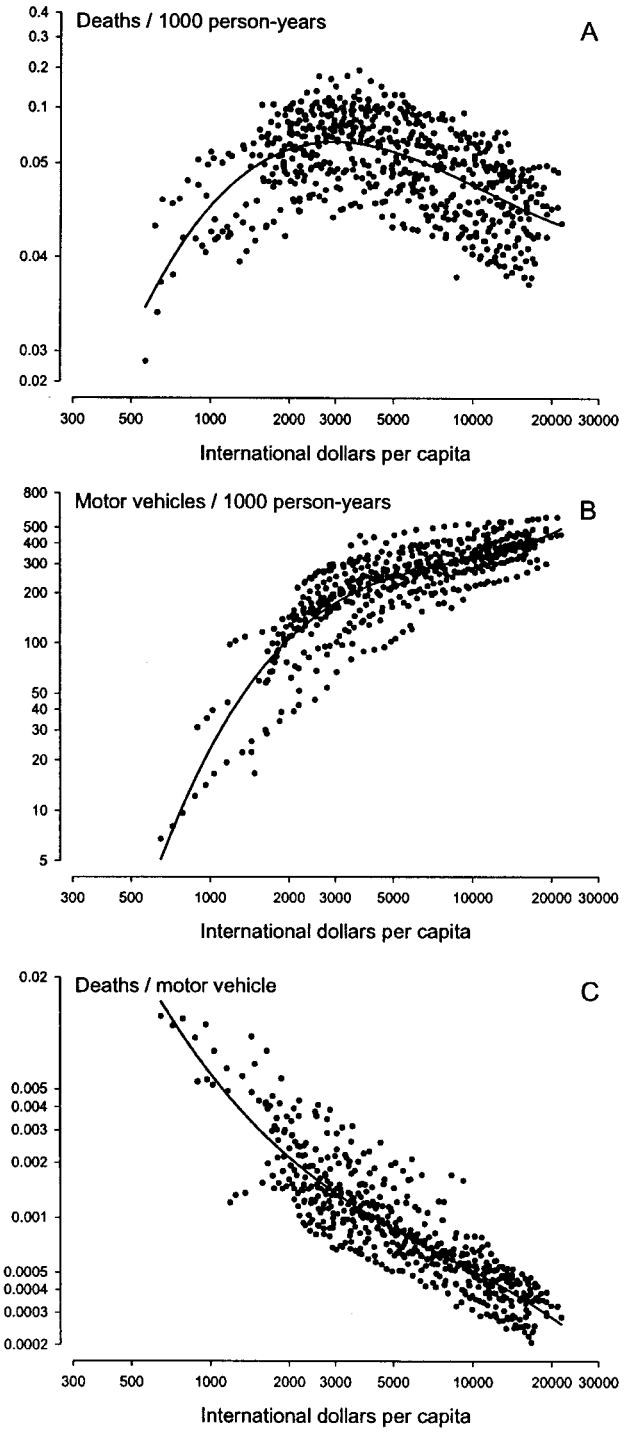

Figure 2 Cubic regression of traffic accident mortality (deaths/1000 person-years), traffic mobility (motor vehicles/1000 person-years) and the fatal injury rate (deaths/motor vehicle) on the level of prosperity (international dollars per capita) (pooled data from 21 OECD countries)

term perspective, it seems to have both negative and positive effects. It leads to mobility growth but could simultaneously stimulate adaptations. This shows that the concept of traffic accidents as a 'disease of affluence' is too simple. The final effect results from the balance between negative and positive developments. Currently, in most industrialized countries the balance appears to be weighed in favour of the positive effects, as mobility growth has levelled off. It seems as if prosperity acts on

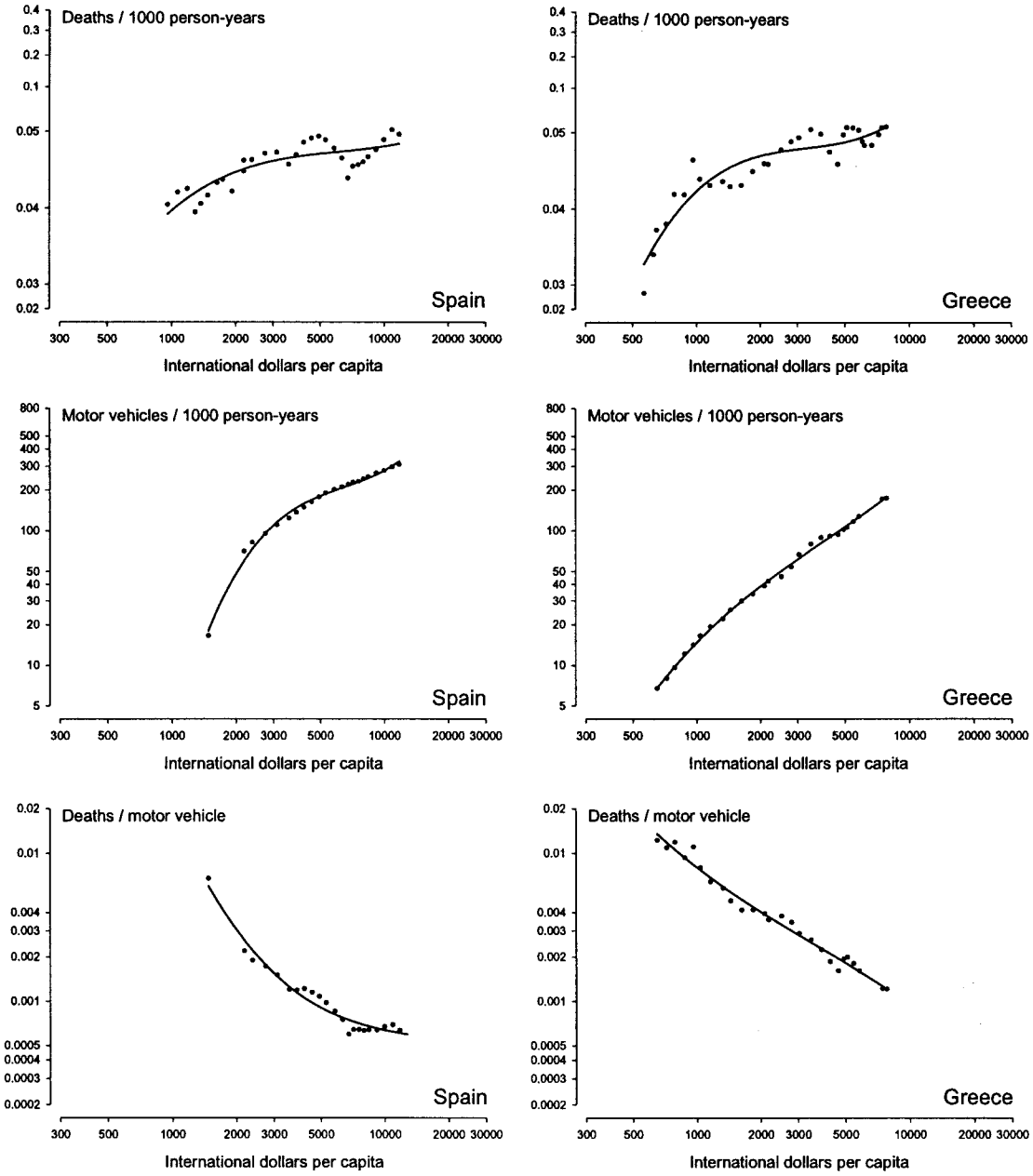

Figure 3 Cubic regression of traffic accident mortality (deaths/1000 person-years), traffic mobility (motor vehicles/1000 person-years) and the fatal injury rate (deaths/motor vehicle) on the level of prosperity (international dollars per capita) in Spain and Greece

traffic accidents in the same way as on other major diseases. In particular, the similarity with cardiovascular diseases is striking: the reversal from a positive into a negative cross-sectional relation reported in our study had previously been found in the field of cardiovascular diseases.[17,18] As in the case of cardiovascular diseases, prosperity growth seems to stimulate adaptation mechanisms, including prevention and improvements in medical care.[29–32]

As in all studies based on existing data sources, our results must be interpreted with care. In the first place, possible registration bias caused by differences in coding of mortality between countries, and on changes in coding practices over the years, must be examined. Differences between countries are probably limited because we restricted our study to a rather homogeneous set of countries: the industrialized world. Possible changes in coding practices over time could be assessed because our file contained data on all external causes of mortality. We found that the declines in traffic accident mortality since the 1970s were combined with declines in non-traffic accident mortality. We could not identify shifts from traffic accidents to non-traffic accidents. Our major finding, the trend reversal in mortality due to traffic accidents, is therefore highly unlikely to be the result of changing coding practices over time. A second issue concerns the use of data on motor vehicle

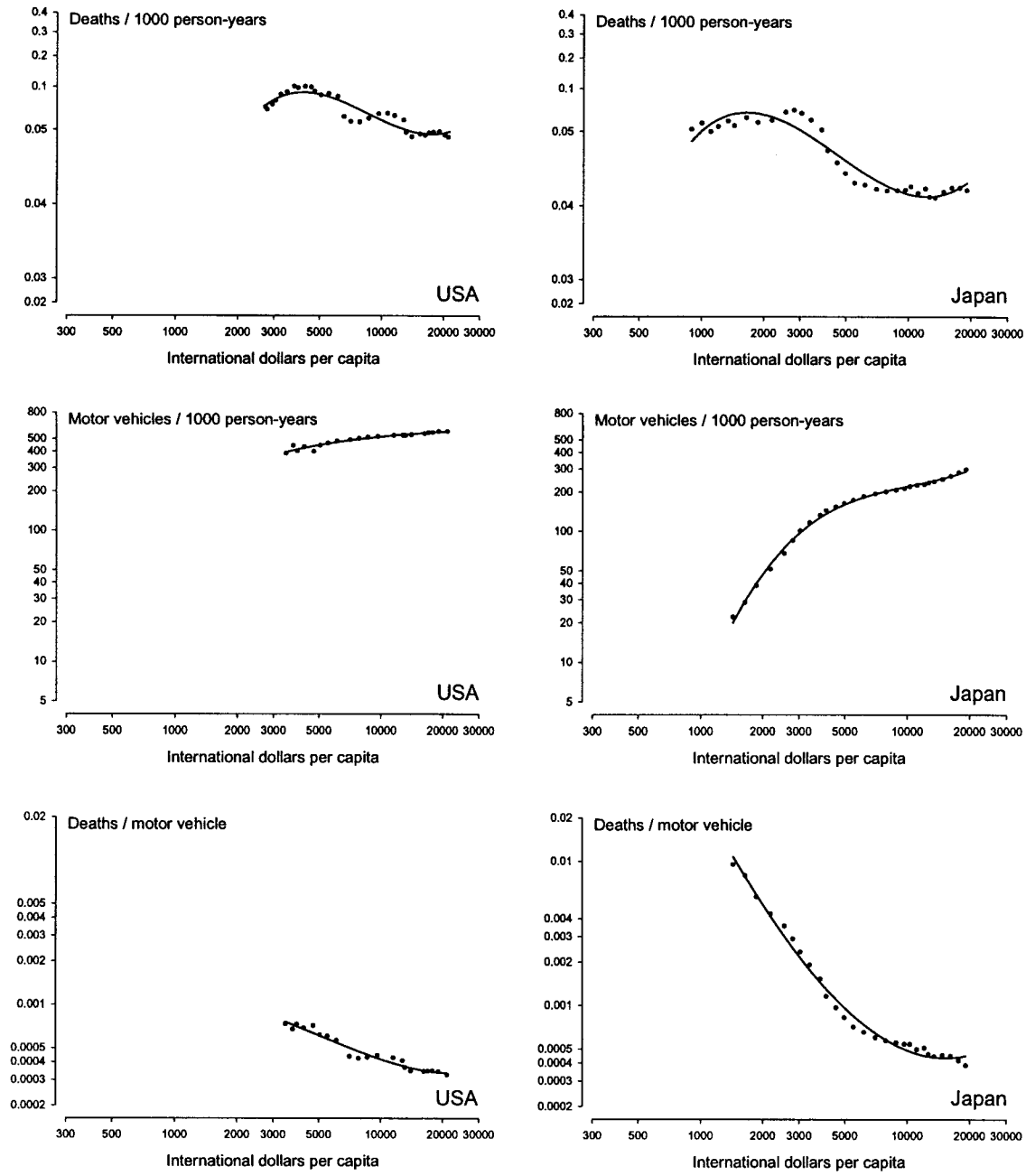

Figure 4 Cubic regression of traffic accident mortality (deaths/1000 person-years), traffic mobility (motor vehicle/1000 person-years) and the fatal injury rate (deaths/motor vehicle) on the level of prosperity (international dollars per capita) in the USA and Japan

ownership as a proxy for traffic mobility. Data on passenger or vehicle miles would have been preferable, because they provide a better measure of exposure.[33] However, we were not able to extract a complete set of reliable data on these parameters for all countries since the early 1960s. Therefore, we had to rely on figures on motor vehicle ownership, as was done in previous studies.[19] It cannot be excluded that one of our major findings, mobility growth levelling off at higher prosperity levels, is partly based on registration bias. This could be the case if a lower growth rate of motor vehicle ownership is compensated by a faster growth rate of the number of passenger kilometres per motor vehicle.

Probably, however, we are dealing with a real phenomenon. A potential saturation of mobility growth has previously been modelled for several countries, using data on the development of vehicle miles in the population.[34,35]

Our results seem to have some importance from a health policy perspective. The concept of traffic accidents as a 'disease of affluence', although too simple, cannot be rejected completely. Up to a certain prosperity level, increasing wealth gives rise to

more traffic deaths. Worldwide, only a limited number of countries have already reached this level. This means that on a global scale an enormous increase in public health damage due to traffic injuries could still be expected, as has been reported previously.[36] The results of our study also suggest that, in general, growing prosperity facilitates adaptations leading to reductions in the fatal injury rates. The current inverse relation between prosperity and traffic accident mortality in the industrialized world is probably explained by these adaptations, including improvements in the traffic infrastructure and trauma care. Recent developments in individual countries have indicated, however, that prosperity growth in itself is not sufficient to reduce the number of traffic deaths. In Spain and Greece, for example, traffic accident mortality has continued to rise after passing the prosperity level which is expected to become protective. Both countries, so far, have been less successful in reducing their fatal injury rates than most other countries within the industrialized world. The fatal injury rate in Spain and Greece is still relatively high. This can probably only be partly attributed to lack of improvement in the traffic infrastructure and trauma care. Lack of compliance with preventive legislation (e.g. seat belt use) could be equally important. This indicates that, regardless of the level of economic development, active policies to reduce the number of traffic deaths should never be neglected. This is further supported by the finding that in some countries the decline in traffic accident mortality seems to have stopped at very high prosperity levels.

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