The relationship between health and GDP in OECD countries in the

very long run

ABSTRACT

This paper uses Johansen multivariate cointegration analysis to examine the relationship between health and GDP for thirteen OECD countries over the last two centuries, for periods ranging from 1820-2001 to 1921-2001. A similar, long run, cointegrating relationship between life expectancy and both total GDP and GDP per capita was found for all of the countries estimated. The relationships have a significant influence on both total GDP and GPD per capita in most of the countries estimated, with 1% increase in life expectancy resulting in an average 6% increase in total GDP in the long run, and 5% increase in GDP per capita. Total GDP and GDP per capita also have a significant influence on life expectancy for most countries. There is no evidence of changes in the relationships for any country over the periods estimated, indicating that shifts in the major causes of illness and death over time do not appear to have influenced the link between health and economic growth.

1. INTRODUCTION

There has been increasing interest in the relationship between health and economic growth over the last few years. The World Health Organisation (CMH, 2001) and the European Commission (European Commission, 2005) have produced extensive reports that have argued for greater spending on health as a means of promoting growth in GDP, for both developed and developing countries.

In the past, it has generally been well accepted that populations in countries with higher levels of GDP will have better health and longer life expectancy, as higher living standards lead to enhanced prevention and treatment of disease (see, for example, the review by Smith (1999)). But the reverse effects, through the influence of better health in raising the level of GDP, may potentially be of equal or even greater importance. Barro (1996), for example, found that health had a substantial positive effect on growth similar to that of education, in a panel estimation of nearly 100 countries from 1960 to 1990.

Understanding the relative significance of both sides of this potentially two-way relationship between health and GDP has important policy implications. If improvements in health do result in long-term sustainable growth in GDP, then policies that promote health may warrant higher priority as a means of instituting "virtuous cycles" that will lead to continued endogenous improvement in both health and GDP. Such policies would be useful not only to stimulate development in poorer countries, but also to maintain growth in those already rich. However, there are many questions about the relationship between health and economic growth that remain unanswered, particularly about the nature and size of the reverse effects that may occur through the influence of health on GDP.

This study seeks to address some of these questions by using very long time series

data to determine if there has been a long term endogenous relationship between health and GDP in each of thirteen OECD countries, and to test if these relationships have been stable over time. The analysis is novel, firstly because it gives measures of both the size and relative significance of the macroeconomic effects of improvements in health for which there is currently very little empirical evidence, particularly for individual countries. Secondly, the estimations cover very long time periods during which there have been marked changes in the causes of ill-health in these countries. The results provide new insights into whether the influence of health on economic growth has remained unaffected by changing circumstances over time, and is therefore likely to still be important for developing countries today, and to continue to be important for OECD countries in the future. Thirdly, the study focuses on a relatively large group of high income countries, for which there has previously been little research in this area. In doing so, it helps to shed light on the current issue facing these countries, of whether the rise in income-related lifestyle factors as primary causes of disease over the last few decades has reduced or even eliminated the positive health benefits of higher levels of GDP that have been observed in the past.

The existing literature suggests that improvements in health can influence GDP both directly and indirectly. Total GDP will increase if longer life expectancy results in an increase in population, so that more people are available to participate in the labour force. But GDP per capita in this situation may be unaffected, or may even decline if capital-to-labour ratios fall as population increases (Acemoglu and Johnson, 2006).

Growth in GDP per capita can occur through changes in productivity, in savings and investment, or in labour supply (Bloom et al., 2004). Healthier workers would normally be expected to make better use of the time and resources available to them,

directly increasing productivity. However, increases in productivity are more likely to occur indirectly through education and human capital effects. Healthier students should achieve more from their learning experiences, but more importantly, longer life expectancy increases the potential benefits and thus the incentive for higher educational attainment.

The positive effects on productivity will be amplified if lower childhood mortality leads to a decline in fertility, increasing both the motivation and the ability of parents to better educate their children (Guest and Swift, 2008). Similarly, longer life expectancy increases the motivation and the ability to save and invest in physical and intellectual capital, so that the growth in human capital that results from improvements in health may be accompanied by growth in capital more generally.

Changes in labour supply as health improves are likely to have more ambiguous effects. Longer life expectancy and higher wages earned by healthy workers can provide greater incentives to work, in addition to the increase in labour supply that occurs as healthy workers find working easier and lose less time to illness. Conversely, the higher lifetime earnings and lower medical costs of healthy workers may reduce the motivation to work. The effects on labour supply can also extend to family members and carers whose working lives are interrupted by the ill-health of others (see CMH (2001) for a survey of this literature).

There is extensive empirical evidence to support the influence of health on productivity and income through these channels. However, most of the previous research has been microeconomic in nature, studying effects on individuals or small groups, and primarily focussing on low income and developing countries (see, for example, the review by Strauss and Thomas (1998)).

Studies of broader macroeconomic effects have shown more mixed results. Among recent papers, Bhargava et al. (2001) found that the effect of health on the growth rates of GDP per capita was positive only for low income countries, in a panel estimation of 92 countries from 1965-1990. Jamison et al. (2005) reported similar results in their estimation of a panel of 53 countries from 1965-1990. They found that the positive effects of health on GDP per capita declined as life expectancy increased, that is, the effects were larger for low income countries with lower life expectancy.

Acemoglu and Johnson (2006) exploited the wave of medical innovations that began in the 1940s in their estimations of the effects of improvements in health in a panel of 59 countries from 1940-1980. The introduction of new drugs and public health measures during this period, such as penicillin and mass immunisation, was followed by a significant reduction in illness and death from infectious diseases, especially amongst children. These innovations resulted in an "epidemiological transition", or a shift in the major causes of death from infectious diseases to degenerative or non-communicable diseases (NCDs), particularly in developed countries. Acemoglu and Johnson (2006) found that the increase in life expectancy that followed these health improvements led to a large increase in population and a smaller increase in total GDP, but the increase in total GDP was not sufficient to compensate for the growth in population. The authors concluded that there was no evidence of any significant positive effects on GDP per capita within the 40 year horizon.

The study by Suhrcke and Urban (2006) also relates to the recent epidemiological transition, but took a different approach by focussing on the effects of a specific disease on economic growth. Cardio-vascular disease (CVD) is the most prevalent of the NCDs, and is now the predominant cause of deaths in developed countries, as well as being a

major contributor to death and ill-health in developing countries. Using a panel of 73 countries from 1960-2000, the authors found that deaths from CVD did significantly reduce growth in GDP per capita in high-income countries, but not in low and middle income countries.

The varied results from this literature raise some interesting questions for research, particularly for high income countries. As noted by Suhrcke and Urban (2006), life expectancy varies very little between high income countries. It is therefore not surprising if panel data estimations which use life expectancy as a proxy for health find that it has little explanatory power for GDP growth in high income countries. Moreover, many of the most important mechanisms by which better health leads to growth in GDP per capita will show their full effects only after very long periods of time. This is particularly true for the growth in both human and physical capital that is generated by the incentive effects of longer life expectancy. Here maximum gains will be achieved only as children born and educated after the increase in life expectancy reach the end of their working lives, perhaps 60 or 65 years later (Bleakley, 2006). The effects will be even more prolonged if a decline in fertility, induced by increasing life expectancy, contributes significantly to growth in human capital.

The extended data series required to show very long term effects like these are available only for high income countries, suggesting that these countries may provide better opportunities for examining the macroeconomic benefits of improvements in health. This paper uses Johansen multivariate cointegration analysis to examine the individual relationship between health and GDP for thirteen OECD countries over the last two centuries. This method avoids the discrimination problems found with panel data, and allows for the non-stationarity and potential endogeneity of both health and GDP,

including testing for exogeneity of each variable.

The data series used in the analysis cover very long time periods, ranging from 1820-2001 to 1921-2001. The data for all countries thus includes the most recent epidemiological transition starting in the 1940s, and for many, it also includes the earlier epidemiological transition in the second half of the nineteenth century, following the industrial revolution in Europe (Acemoglu and Johnson, 2006). In the early 1800s, Europe was only starting on the path of industrial development, so the relationship between health and GDP in European countries since that time should provide some guide for the similar if accelerated path followed by developing countries more recently.

The results show that there is a similar long run cointegrating relationship between life expectancy and both total GDP and GDP per capita for all of the countries estimated. This relationship has a significant influence on both total GDP and GPD per capita in nearly all of the countries estimated, with 1% increase in life expectancy resulting in an average 6% increase in total GDP and 5% increase in GDP per capita in the long run. Total GDP and GDP per capita also have a significant influence on life expectancy for most countries. There is no evidence of any change in the relationships for any country over the periods estimated, indicating that shifts in the major causes of illness and death over time do not appear to have influenced the link between health and economic growth.

Methodological differences make comparison of the magnitudes of the cointegration estimates with those in other studies more difficult. However, the long-run results are generally similar in size to those found in the production function models of Beraldo et al. (2005) and Bloom et al (2004), and to most broader cross-country panel data estimations, such as Barro (1996). The results of other studies, such as Acemoglu

and Johnson (2006) appear to be more comparable to the short-run coefficients of the VECM.

The rest of the paper is organised as follows. Section 2 describes the data and methodology to be used in the estimations. Section 3 discusses the results of the estimations for each country in more detail, while Section 4 provides some concluding comments.

2. DATA AND METHODOLOGY

The aim of this study is to determine if there is a long term endogenous relationship between health and total GDP, or between health and GDP per capita, for each country, and whether these relationships have remained constant over time. Data on other variables often included in growth regressions, such as investment and education, are not included because they are not available for the extended time periods used here. This should not cause problems for the estimates as a cointegrating relationship is invariant to extensions of the information set, that is, if a long run or cointegrating relationship does exist between health and GDP, the estimates will not be significantly affected by the presence or absence of additional variables (Juselius, 2006, p.11).

2.1 DATA

The data on total GDP and GDP per capita for each country were taken from (Maddison, 2003), and are all expressed in terms of 1990 international dollars. Data on life expectancy at birth for each country were taken from the Human Mortality Database,

which provides comparable data for each country calculated by a uniform method.[1] Life expectancy is the only measure of health status that is available for the extended time periods used here. It suffers from the disadvantage of being an incomplete measure of population health because it does not include improvements, such as better nutrition, that may increase worker productivity but have little effect on the length of life (Bhargava et al., 2001). However, this under-measurement should be of less significance in a very long run analysis if most long term gains in human and physical capital are the result of the incentive effects of having a longer life span to recoup the investment, as suggested by the theoretical literature discussed in Section 1.

Figure 1 shows the changes in life expectancy and GDP for England and Wales over the period, which are representative of the patterns observed in the other OECD countries. In 1841, England and Wales were in the early stages of the road to industrial development, with life expectancy of only 41 years, and GDP per capita of $1900. Life expectancy was relatively constant at around 40 - 45 years until the late 1870s, when it began to rise steadily. The falling mortality rates underlying this upward trend were the result of the economic and social changes that followed the Industrial Revolution in Europe, as better nutrition and advances in public hygiene improved health and reduced deaths, particularly from infectious diseases. This period marks the first epidemiological transition (Omran, 2005).

There was a sharp increase in deaths around the time of the First World War and the influenza pandemic in 1918-1919, and a similar but smaller effect during the Second World War (Figure 1). Apart from these episodes, the increase in longevity continued at

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[1] *Human Mortality Database,* University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany), available at www.mortality,org .

a similar rate until about 1950. Since the second epidemiological transition, which started in the late 1940s, the rate of increase in life expectancy has slowed somewhat as NCDs have replaced infectious diseases as the major causes of death in developed countries.

Table 1 gives the relative changes in life expectancy, total GDP and GDP per capita over the whole period of estimation for each country. For comparison purposes, it also gives the relative changes for each country from 1921 to 2001, which is the longest period that is common to all countries. There have been large percentage increases in both GDP and GDP per capita in the OECD countries as life expectancy has increased, with an average 40.1% increase in GDP and 12.6% increase in GDP per capita for each 1% change in life expectancy over the full period of estimation, and 30.4% and 14.6% respectively for each 1% change in life expectancy from 1921-2001. These simple comparisons of long-run changes suggest potentially significant relationships between health and output, but there are clearly many other factors that may have lead to increases in GDP and GDP per capita over time, as well as improvements in health. The strength of the cointegration techniques used here is that they allow the identification of the unique long-run relationship that may exist between life expectancy and GDP in each country, so that the size and direction of the relationships can be estimated independently of any other long-run influences on GDP growth.

2.2 METHODOLOGY

Stationarity testing of the variables was performed using Augmented Dickey-Fuller (ADF) tests. All three variables in log form, life expectancy (LE), total GDP, and GDP per capita (GPC), for all the included countries were non-stationary but their first

differences were found to be stationary. That is, all variables (in log form) were I(1).[2] It

is therefore appropriate to use cointegration analysis to estimate the relationships between

the variables, provided that the method used allows for the possible joint causality of the

variables as suggested by the previous literature discussed in Section 1.

The Johansen multivariate cointegration method was chosen for this reason,

because it provides estimates of both the long run and short run relationships within a

system of equations in which all variables are potentially endogenous. The system of

equations estimated in the Johansen method is a vector error correction model (VECM)

derived from a standard unrestricted vector autoregressive model (VAR) of lag length k.

The VAR system of equations is algebraically re-arranged into a VECM, written as:

$$\Delta z_t = \Gamma_1 \Delta z_{t-1} + \ldots + \Gamma_{k-1} \Delta z_{t-k+1} + \Pi z_{t-1} + \mu + \Psi D_t + \varepsilon_t \qquad (1)$$

where z_t is the vector of variables, μ is a vector of constants, and D_t a vector of other

deterministic variables such as a time trend. In order to distinguish between the effects of

health on total GDP and on GDP per capita, two estimations were performed for each

country, the first with life expectancy (LE) and total GDP (GDP) as the vector of

variables in z_t, and the second with LE and GDP per capita (GPC).

The first group of terms on the right hand side of equation (1), up to and including

Δz_{t-k+1}, represents the short run lagged effects of differences in the variables in z, or Δz,

on each variable in the system. The next term, Πz_{t-1}, is the error correction term (ECT)

that represents the long run cointegrating relationship between the levels of the variables

in z. The number of cointegrating relationships between the variables is given by the

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[2] Results of the ADF tests are available on request.

rank (r) of the matrix of long run coefficients Π.

If a cointegrating relationship exists between the variables, Π can be factorised into $\Pi = \alpha\beta'$, where β' is the coefficients on the individual variables in the long run or cointegrating vector and α is the coefficient on the ECT itself, which represents the speed of adjustment to disequilibrium. If α is not significantly different from zero in one of the equations of the system, then the long run cointegrating relationship represented by the ECT does not have a significant influence on the dependent variable in that equation. This variable can then be said to be weakly exogenous for the long run relationship (Johansen, 1988, 1991; Johansen and Juselius, 1990).

Johansen uses a canonical correlation technique, solved by calculating eigenvalues (λ_i), to provide a set of eigenvectors that form the maximum likelihood estimate of the long run coefficients (β). A likelihood ratio (LR) statistic, the Trace statistic, is used to test the significance of the eigenvalues and thus to determine the maximum number of statistically significant vectors (r) within β.

Lag lengths for the Johansen estimation were determined by LR tests of paired comparisons of different lag lengths in the original VAR system. The choice was confirmed by Lagrange-Multiplier (LM) tests of the residuals which showed that the included lags were sufficient to avoid serial correlation in all systems. Doornik-Hansen tests for normality indicate that the residuals in all systems are free from skewness, although there is evidence of non-normality in some equations due to kurtosis. This should not cause problems for the estimates because, as noted by Johansen (1995, p. 29), the "asymptotic properties of

the methods only depend on the i.i.d. assumption of the errors".[3]

Deterministic components were included in the cointegrating relationships where indicated by tests of the joint hypothesis of both the rank order and the deterministic components, as described by Johansen (1992). Dummy variables were also included in the short run components for all countries for the period of 1914-1919 to allow for the effects of the First World War and the subsequent influenza pandemic, and for 1939-1945 for the Second World War. For Spain, the period of the second dummy variable was extended to 1936-1945 to allow for the effects of the Spanish Civil War.

3. ESTIMATION RESULTS

Tables 2 and 3 show the results of the trace test for the rank (r) of the matrix of long run coefficients (β), which indicates the number of cointegrating vectors between the variables. In all cases, the null hypothesis of $r = 0$ is rejected, but $r = 1$ cannot be rejected. This means that there is a long run or cointegrating relationship between LE and GDP, and between LE and GPC, in all of the thirteen countries tested.

3.1 LONG RUN RELATIONSHIPS

Table 4 gives the β coefficients of the long run relationship between LE and GDP for each country, together with the α coefficients on the long run relationship in the error-correction equation for each variable.[4] The β coefficients indicate that 1% increase in LE in the long run is associated with an increase in total GDP ranging from just under 3% in

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[3] Results of residual tests are available on request.

[4] The results were obtained using CATS in RATS, version 2 (Dennis et al, 2005).

the case of England and Wales to around 9% for Australia, Canada and Norway, with an average increase across all thirteen countries of 6.124%. The α coefficients on the long run relationship in the equations for dGDP are significant for eleven countries, with the only exceptions being Finland and Spain. This implies that, for most of the OECD countries estimated, the long run relationship between LE and GDP has resulted in significant increases in total GDP as LE has increased over the period. The α coefficients on the long run relationship in the equations for dLE are also significant for nine countries. These results confirm the dual endogenous nature of the relationships suggested by the previous literature, as rising GDP has simultaneously led to an increase in LE for most countries over the period.

The result of the estimations between LE and GPC in Table 5 show very similar patterns for both the α and β coefficients as those for total GDP, except that the β coefficients are generally smaller. Here, 1% increase in LE in the long run is associated with an increase in GPC ranging from around 2% to 7%, with an average increase across all countries of 4.995%. The α coefficients show that, as before, the long run relationship between LE and GPC has resulted in significant increases in GPC as LE has increased for eleven countries, with a similar endogenous increase in LE as GPC has increased in eight countries.

The α coefficients in Tables 4 and 5 represent the proportion of any disequilibrium in the long run relationship that will be corrected each year, or the speed of adjustment to equilibrium, and thus can also be used to characterise the dynamics of the relationships. For example, the average size of the α coefficients in the equations for dGPC in Table 5 is equal to 0.035. This implies that, on average, only 3.5% of the long

run increase in GPC that results from an increase in LE will take place each year. As discussed previously, the β coefficients in Table 5 indicate that an increase of 1% in LE leads to a long run increase of around 5% in GPC on average across the thirteen OECD countries. In this case, the α coefficients show that 1% increase in LE will result in an average increase in GPC of only 0.17% in one year. If there are no further changes in LE, it will take 20 years before 50% of the adjustment, or an average increase of 2.5% in GPC, occurs, and it will be 65 years before 90% of the adjustment, or an average increase of 4.5% in GPC, occurs. The very slow rate of adjustment in GPC shown here supports the arguments by Bleakley (2006) and others that maximum gains to economic growth from improvements in health may only be achieved after very long periods of time.

The long run effects of LE on total GDP shown in Table 4 are generally larger than the effects on GPC in Table 5, but this is to be expected if part of the increase in total GDP is a consequence of population growth, in addition to the productivity effects that increase GPC. In this case, the size of the difference in the β coefficients between GDP and GPC will be affected by individual factors that may have influenced population growth in each country over the period, such as the age structure of the population or migration. For example, the decrease in the β coefficients between the estimations with GDP and GPC is greatest in the settler economies of Australia and Canada, whilst at the other extreme, England and Wales is the only estimation in which the coefficient on GDP is actually smaller than that on GPC. These three estimations are for the countries in the group that have been most affected by migration during the period, inward and outward respectively, suggesting that the mass movement of primarily younger able-bodied workers may have had some influence on the effects of LE on total GDP.

Other variations in results that are common to the estimations with both GDP and GPC may also be due to differences in individual countries or groups of countries, such as the weak exogeneity of LE that is shared by the Scandinavian countries of Denmark, Norway and Sweden. The Scandinavian countries have generally achieved longer LE earlier in the period than the other countries in the group, suggesting that health in these countries may have benefited from some more specific influences. For Spain especially, the weak exogeneity of GDP and GPC for the long run relationship may have been affected by the long aftermath of the extended period of conflict in the middle of the period, as both GDP and GPC remained depressed for much longer in Spain than in the other European countries after the end of the Second World War.

The size of the β coefficients of the long run relationships between LE and GDP, and between LE and GPC, in Tables 4 and 5 are generally considerably smaller than the simple comparison of relative long-run changes in the variables shown in Table 1. This is to be expected because growth in GDP and GPC can occur as a result of many other factors in addition to improvements in health. The only case in which the β coefficient is the same magnitude as the long-run relative change in Table 1 is in the relationship between LE and GPC for Spain. This is consistent with the weak exogeneity of GPC for Spain discussed above, suggesting that growth in GPC in Spain has been more affected by factors other than health over the period.

3.2 SHORT RUN RELATIONSHIPS

Tables 6 and 7 show the significant lags on the short run variables in each equation of the VECM, for the models with total GDP and GPC respectively. The most

noticeable feature is that most of the short run coefficients for LE are not significant in the equations for GDP and GPC, that is, changes in LE have no significant short run effects on GDP or GPC in most countries. The short run coefficients which were significant were all small and negative, ranging in value from -0.130 to -0.502, except for those for France which were small and positive, all around 0.3 in value.[5] The negative effects in the short run are most likely to be a consequence of the increase in population that is initially expected to follow an improvement in health, particularly in lower age groups.

The results indicate that changes in LE may have no significant effects, or even small negative effects on GDP and GPC in the short run, even though the long run results demonstrate that rising LE has led to significant increases in both GDP and GPC in most of these countries in the longer term. The difference in the results over time for these countries is consistent with the very slow rate of adjustment shown in the long run relationship, and lends further support to the argument that improvements in health may take many years to lead to greater economic growth. It may also help to explain the divergences in results among more recent studies that have covered only relative short time periods.

Conversely, both GDP and GPC show significant effects on LE in the short run in most countries in Tables 6 and 7. Short run lags of GDP and GPC are significant in the equations for LE for nine out of the thirteen countries, even in countries where the effects of increases in GDP and GPC on LE do not continue into the long run, such as Norway and Sweden. The significant coefficients were again small, ranging in value from 0.050

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[5] Full results of all the short run coefficients are available on request.

to 0.392, and most were positive, indicating the beneficial effects of increased income in health. The results suggest that the benefits of economic growth in generating improvements in health may be more likely to be emphasised because they are more immediately apparent than the reverse effects, particularly in models that are limited to shorter term effects.

3.3 COMPARIONS WITH OTHER STUDIES

The long run effects of LE on GPC shown in Table 5 appear to confirm that, for most of the OECD countries, longer LE has lead to the gains in productivity suggested by the previous theoretical literature discussed in Section 1. It is difficult to make direct comparisons with the results of previous empirical studies due to the different methodology used here, as well as the much longer time period. The coefficients of a cointegrating relationship between non-stationary variables estimated in levels, as in this paper, represent a long run steady state equilibrium relationship. Models estimated in growth or differenced forms do not include a long run equilibrium relationship, so no direct quantitative comparison can be made between the coefficients of previous studies using these methods and the long run estimates produced here. The closest equivalents to the coefficients estimated in growth or differenced models are the short run coefficients of the ECM discussed in Section 3.2 above. Even in the short run, however, the estimates may not be directly comparable because the size of the coefficients in the growth models may be affected by the absence of the ECT which represents the long-run cointegrating relationship between the variables.

As discussed in Section 1, there are relatively few other studies on OECD countries, and they have generally reported mixed results. Acemoglu and Johnson (2006)

used 10 yearly data from 1940-1980 for a worldwide sample of 59 countries to estimate a series of cross-sectional models that are described as analogous to growth regressions with country fixed effects. Using an instrumental variable for changes in life expectancy, referred to as "predicted mortality", the authors concluded that increases in life expectancy had led to a significant increase in population, but only "a relatively small effect on total GDP at first, with a somewhat larger effect over time" (Acemoglu and Johnson, 2006, p. 27). However, they reported that relatively large standard errors made it impossible to identify the exact magnitude or timing of these effects on total GDP.

Acemoglu and Johnson (2006) also investigated the impact on GDP per capita and GDP per working age population. They found effects which varied in statistical significance but were always negative, with coefficients initially around -1.30, as well as smaller but still negative impacts of around -0.90 over longer differences of up to 40 years. The authors concluded that there was no evidence of a positive impact of life expectancy on GPC. As noted by Suhrcke and Urban (2006), some of the explanation for findings such as these in cross-sectional models may be due to the problems incurred by the very limited variability of life expectancy in panel data from high income countries. However, although the coefficients of Acemoglu and Johnson (2006) are larger in size, the varying significance and negative sign of the estimates is similar to the short run coefficients of the VECM discussed in Section 3.2 above. Other authors, such as Beraldo et al. (2005), who used a production function approach to examine the effects of health expenditure in 19 OECD countries between 1971 and 1998, have found a statistically significant impact on GPC that was more similar to the long run effects found here, with spending on health accounting for a share of around 16 - 27% of growth rates.

Estimations for a broader sample of countries have shown more consistent results. For example, Bloom et al (2004) used an extended production function model to analyse a worldwide panel of 104 countries from 1960 to 1990. In a semi-log specification, the authors found that a one-year improvement in life expectancy will lead to around 4% increase in GPC. Bloom et al (2004) do not indicate the average life expectancy of their sample, but the average life expectancy for the thirteen OECD countries included in this study over the period estimated by Bloom et al (2004) was approximately 74 years. Using this figure, the estimate of Bloom et al (2004) suggests that 1% increase in average LE for the OECD countries over the period 1960-1990 would be expected to result in around 3% increase in GPC. This is on a similar scale to the long-run increases found here, and is quite close to the long-run coefficients estimated for several of the included countries such as the Netherlands and Switzerland.

Other panel data estimations have also shown similar results. Cross-country panel data growth estimations that incorporate health effects typically use the differenced or growth form of GPC as the dependent variable, with the initial level of life expectancy in each country at the start of the period as the explanatory variable representing health effects. Barro (1996), for example, found that health had a substantial positive effect on growth similar to that of education, in a panel estimation of nearly 100 countries from 1960 to 1990. Barro (1996) estimated that 1% rise in initial life expectancy would result in an increase in the growth rate of GPC of 0.0423%. This would be equivalent to an increase in GPC of around 2.3% after 20 years, which is similar to the average increase of around 2.5% in GPC after 20 years calculated in Section 3.1 above.

Bloom et al (2004) surveyed the results of 13 cross country growth regressions that included health in the form of life expectancy, and concluded that "investigators

generally find that it has a significant positive effect on the rate of economic growth".

Bloom et al (2004) report that the majority (10) of the studies surveyed found coefficients on the life expectancy variable similar to those estimated by Barro (1996). Coefficient estimates ranged from 0.019 to 0.073, with an average value of 0.046. This indicates an expected increase in GPC on average of around 2.46% after 20 years, which is virtually identical to the average increase in GPC after 20 years found in the countries estimated here.

Bhargava et al. (2001) also found similar effects of health on the growth rates of GPC in their panel estimation of 92 countries from 1965-1990, but only for low income countries. The authors estimated that a 1% change in the adult survival rate was associated with approximately 0.05% increase in the growth rate of GPC in low income countries, with similar results when life expectancy was used as the health variable. This result is equivalent to an increase in GPC of around 2.65% after 20 years, similar to the result found by Barro (1996), and that calculated in Section 3.1 above. However, Bhargava et al. (2001) found that for highly developed countries, the estimated effects of adult survival rates on growth rates was negative.

Jamison et al. (2005) reported similar coefficients of 0.35-0.49 on adult survival rates in their estimates of panel growth regressions from 1965-1990. Using alternative specifications that decomposed income growth into its components, the authors concluded that better health contributed 0.23% per year on average to income growth rates of the included countries during the period. However, as with Bhargava et al. (2001), Jamison et al. (2005)found that this contribution varied from 0.5% in countries such as Honduras, Bolivia and Thailand, to .only 0.1% per year in countries with initially high levels of adult survival rates. As discussed earlier, the differences in the coefficients

between low and high income countries in these studies may be due to the very limited variability of adult survival rates and life expectancy among high income countries, with the result that these measures of health have little explanatory power for GPC growth when high income countries are estimated as a separate group.

Weil (2005) used a methodology that incorporated and compared results from a large number of microeconomic studies to measure the proximate or direct effects of an increase in adult survival rates. The study found that these direct effects alone would result in an increase in GPC equal to around 60% of that found by Bloom et al (2004). Using the figures for average LE for the 13 included countries for 1960-1990 as above, Weil's estimate suggests that the direct effects alone of 1% increase in LE would lead to an increase of around 1.8% of GPC. Weil (2005, p. 39-40) concluded that "the effects of health on income….are large" and further argued that there was no doubt that "accounting for health's indirect effects would yield a larger answer".

Several more recent microeconomic studies have reported similar conclusions, demonstrating large and significant benefits to human capital accumulation from single specific events that changed health status. For example, Bleakley (2007) and Jayachandran and Lleras-Muney (2008) have shown that interventions such as hookworm eradication and reductions in maternal mortality resulted in around 4% increase in education in those affected, while Fortson (2008) found significant large negative effects on educational attainment in all children living in areas with higher levels of HIV.

Jayachandran and Lleras-Muney (2008) used an estimate of the returns to schooling to further quantify their results. The authors calculated that an estimated reduction in life expectancy from HIV/AIDS in South Africa of 10.2% at age 15 lowers annual income by 1.5-2.5% through the effects of shortened time horizons on years of

schooling alone. This estimate of the effects of an increase in education is lower than the elasticities found here, but the gains in GPC estimated in this study include both direct and indirect effects of all causes of improvements in life expectancy, some of which may take very long periods of time to develop. The elasticities estimated by Jayachandran and Lleras-Muney (2008) are derived from a single specific cause of increase in life expectancy (a sudden drop in maternal mortality risk) over a relatively short period of time (1946-1953).

3.4 STABILITY OF THE RELATIONSHIPS

The stability of the long run coefficients for each country was investigated by recursive estimation, in order to determine if the relationships have changed over time. The recursive estimation procedure tests the difference between $\beta^{(n)}$ and $\beta^{(T)}$, where $\beta^{(T)}$ is the full sample estimate of the cointegrating vector. $\beta^{(n)}$ is obtained by successively estimating the model using increasing subsamples from ($t = n$) to ($t = T$), where ($t = 1, . . . n$) provides the base sample for the recursive estimation. The test statistic, $Q_T^{(n)}$, is derived from Hansen and Johansen (1999). To test parameter constancy over the whole period, all of the models were estimated using both forward and backward recursion, that is, the first half of the sample was used as the base to recursively test the stability of the parameters in the second half of the period, and vice versa.

Figures 2 and 3 show the results of the stability tests for the β coefficients in the relationship between LE and GPC for Sweden, which is used here as an example because it has data for the longest time period of the countries tested (1820-2001). The test statistic labelled "$X(t)$" represents the estimated cointegrating relations as a function of

the short run dynamics and deterministic components, whereas the test statistic labelled "*R1(t)*" is corrected for the short run effects. *R1(t)* represents the "clean" cointegrating relation which is actually tested for stationarity to determine the cointegrating rank, and provides the estimated β coefficients shown in Table 5. All the test statistics in Figures 2 and 3 are indexed so that the 5% critical value is equal to 1.00, for ease of comparison. In both Figure 2 and 3, the test statistics are well below the 5% critical value for the whole period, indicating that there has been no significant change in the coefficients of the long run cointegrating relationship between LE and GPC for Sweden over the period of estimation.

Similar results were obtained for the other recursive estimations, both for the relationships between LE and GPC, and between LE and GDP, for all thirteen countries tested.[6] The results of the stability tests confirm that the long run relationships found here between longer life expectancy and economic growth have been stable over very long time frames of up to 180 years. There does not appear to be any evidence that changes in the major causes of illness and death following the epidemiological transitions of either the 19th or 20th centuries have caused any breaks in the relationships. Similarly, the relationships do not appear to have changed even though LE has increased well beyond the usual end of the working life at round 60-65 years, which has occurred in all of the countries in the test group over the last fifty to seventy years.

The stability of the relationships between health and GDP over time found here suggest that the benefits to economic growth in these countries have come from the productivity and incentive effects of having a longer life in general, rather than from

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[6] Results of recursive estimations for all the countries tested are available on request.

reductions in any specific illness or group of illnesses, or changes in the age group most affected. If this is the case, then the shift from infectious diseases to NCDs as the major cause of death in developed countries should only affect economic growth to the extent that these degenerative or "lifestyle" diseases are more resistant to prevention and treatment, so that it becomes more difficult to maintain the previous rate of increase in the length of life.

However, the results found here do not discriminate amongst mechanisms and therefore cannot provide any definitive answer to this question. Although all age groups have benefited from the increase in life expectancy in OECD countries over the last two centuries, the gains have not been uniform across ages. For most of the period estimated here, the decline in death rates was most marked amongst children and females of child-bearing age, with older age groups benefiting more over the last few decades (Omran, 2005). Higher death rates amongst the young may have very different consequences for investment planning than deaths amongst the old. In this case, other mechanisms may be at work to contribute to the stability of the relationships found here.

4. CONCLUSION

Better health can lead to economic growth not only through an increase in total GDP as population increases, but also more importantly, through long term gains in human and physical capital that raise productivity and per capita GDP. The thirteen OECD countries tested here all show long run cointegrating relationships between life expectancy and both total GDP and GDP per capita, and the coefficients of these relationships have remained stable over very long time periods, ranging from 80 to 180 years. In most of the countries tested, the long run relationships have led to significant

increases in both total GDP and GDP per capita as life expectancy has increased, and to similar endogenous increases in life expectancy as GDP has risen.

For developed countries, the results suggest that improvements in health can continue to make valuable contributions to economic growth, even though degenerative and non-communicable diseases are now the main concern in these countries, rather than the infectious diseases that have led to the major gains in the past. There are also implications for developing countries seeking to emulate the growth path of the OECD countries over the last two centuries. If each 1% increase in life expectancy has contributed an average 5% to growth in GDP per capita in Europe over this period, then policies that promote better health in developing countries deserve high priority for their potential economic benefits, not just for humanitarian or quality of life motives.

Many questions remain for further research. This study has used a simple model in order to examine the basic relationships for the longest possible periods. As discussed earlier, the long-run cointegrating relationship between health and GDP found here will not be significantly affected by the presence or absence of additional variables. However, multiple cointegrating relationships are possible in models containing more than two variables, and the inclusion of other relevant variables suggested by the previous literature may reveal the existence of additional simultaneous long run inter-relationships involving other aspects of health and GDP. More complex models for individual countries or groups of countries, possibly including measures of health that include both morbidity and mortality, may thus help to explain the source of the gains in GDP in more detail, and to account for some of the difference in the results between countries. Including changes in morbidity, in particular, may show short run effects on GDP that have not been observable here, as less serious illnesses that reduce productivity

temporarily but do not reduce life expectancy may also reduce GDP in the short run. Unfortunately, data on additional variables such as these are only available for relatively recent time periods, so that more detailed estimations of this type cannot be undertaken over the very long time frames analysed here.

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Figure 1: Life Expectancy, total GDP and GDP per capita for England and Wales (1841 - 2001)
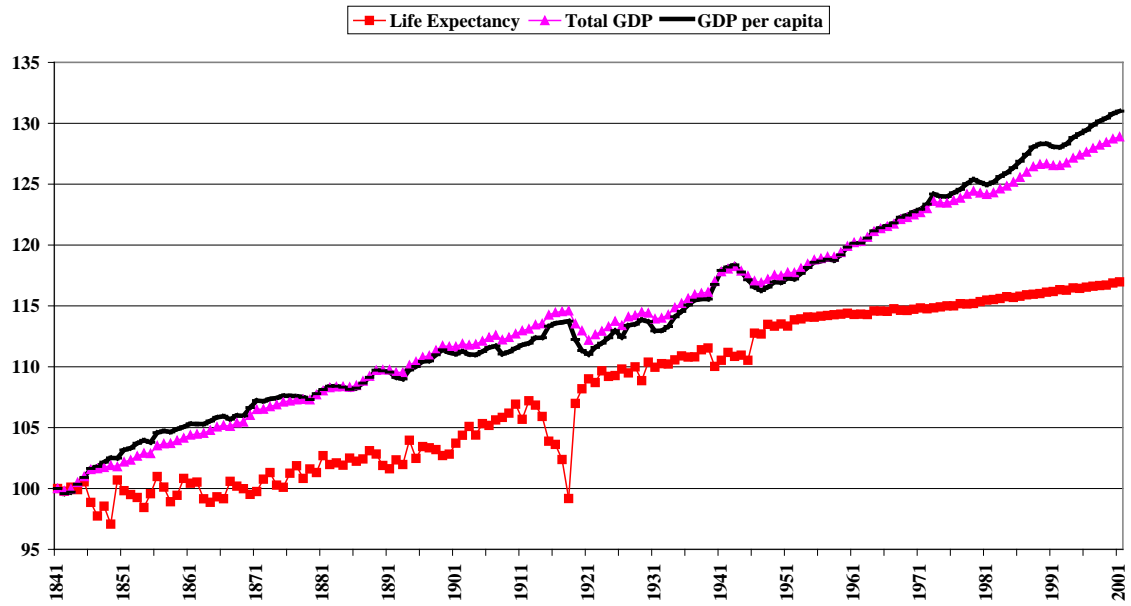**(ln form, indexed, 1841 = 100)**

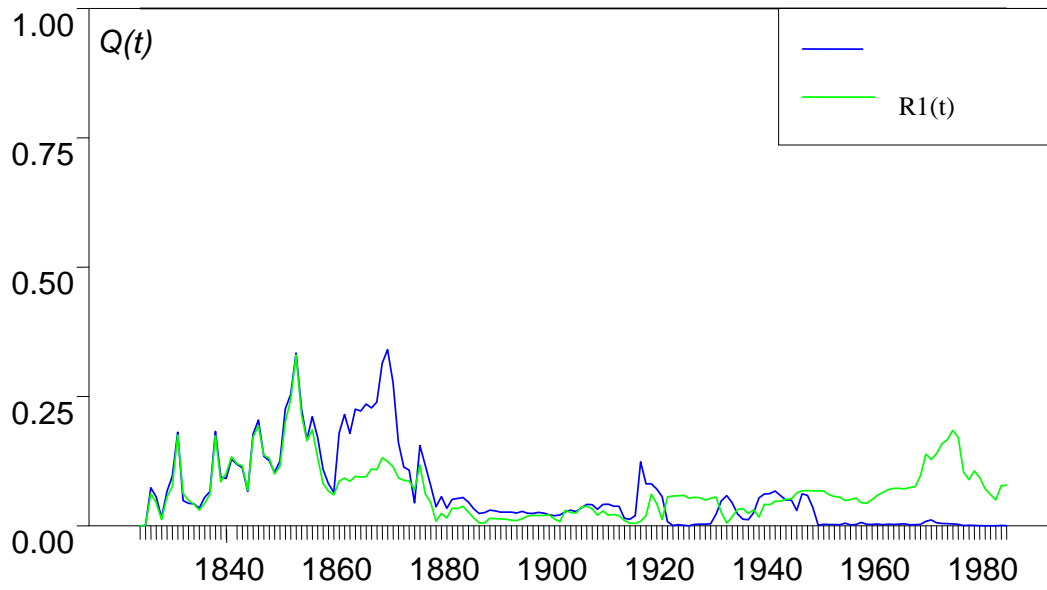**Figure 2: Test of Beta Constancy for Sweden (LE and GPC)**

Base period: 1986-2001

Figure 3: Test of Beta Constancy for Sweden (LE and GPC)
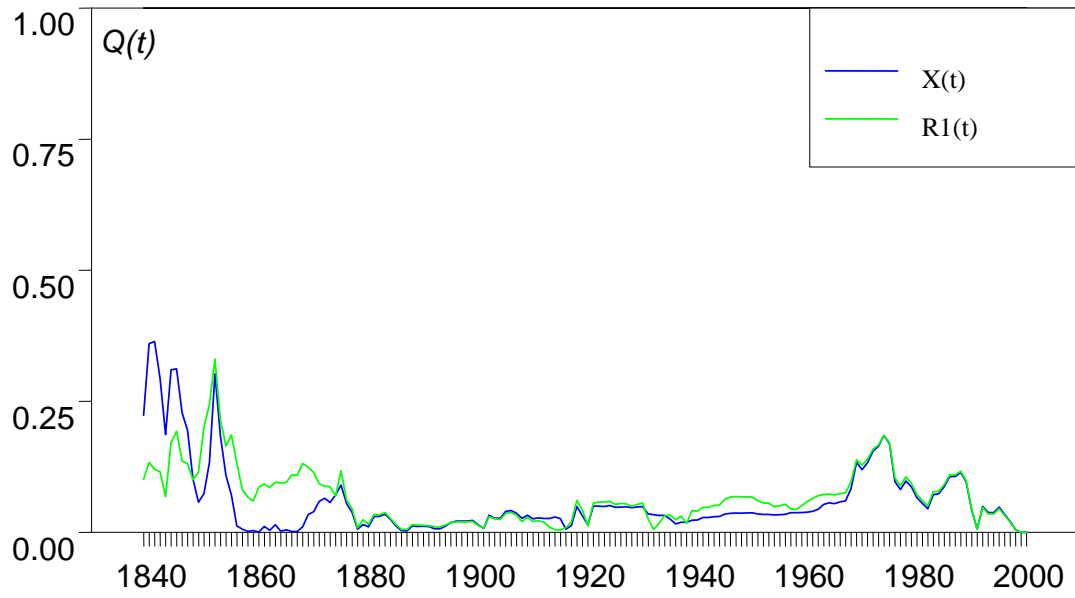
Base Period: 1825-1840

	Full period of estimation			1921-2001		
	Change in LE (%)	Change in GDP (%) relative to change in LE (%)	Change in GPC (%) relative to change in LE (%)	Change in LE (%)	Change in GDP (%) relative to change in LE (%)	Change in GDP (%) relative to change in LE (%)
Australia 1921-2001	31.7%	46.7	10.9	31.7%	46.7	10.9
Belgium 1846-2001	106.8%	26.7	10.6	42.9%	14.1	9.7
Canada 1921-2001	39.71%	56.0	14.2	39.71%	56.0	14.2
Denmark 1835-2001	100.9%	67.3	15.7	24.7%	35.9	20.5
England/Wales 1841-2001	88.3%	25.0	10.7	34.6%	14.9	10.2
Finland 1878-2001	99.7%	44.4	16.4	49.3%	33.7	19.9
France 1899-2001	75.5%	12.8	8.27	50.7%	18.6	11.6
Italy 1872-2001	175.8%	14.5	6.8	62.4%	16.9	10.5
Netherlands 1850-2001	97.4%	47.5	8.4	31.6%	32.7	12.3
Norway 1865-2001	56.6%	83.2	30.1	28.2%	54.9	31.1
Spain 1908-2001	92.2%	16.7	7.6	89.5%	13.7	6.8
Sweden 1820-2001	98.7%	58.7	16.4	31.0%	33.9	21.6
Switzerland 1876-2001	100.5%	21.7	7.6	38.9%	23.0	11.0

Table 1: Comparison of changes in Life Expectancy (LE), total GDP and GDP per capita (GPC) in the OECD countries

Table 2: Life Expectancy (LE) and total GDP
Rank Test for the determination of the number of cointegrating vectors

	Null	Eigenvalues	Trace Statistic	*p*-value
Australia	r = 0	0.424	49.988*	0.000
1921-2001	r = 1	0.085	6.899	0.160
Belgium	r = 0	0.282	51.561*	0.000
1846-2001	r = 1	0.012	1.804	0.817
Canada	r = 0	0.477	57.392*	0.000
1921-2001	r = 1	0.101	8.080	0.105
Denmark	r = 0	0.328	70.738*	0.000
1835-2001	r = 1	0.035	5.850	0.228
England/Wales	r = 0	0.363	78.583*	0.000
1841-2001	r = 1	0.052	8.260	0.097
Finland	r = 0	0.170	22.505*	0.001
1878-2001	r = 1	0.003	0.396	0.529
France	r = 0	0.286	36.267*	0.000
1899-2001	r = 1	0.036	3.525	0.060
Italy	r = 0	0.196	29.704*	0.000
1872-2001	r = 1	0.016	2.025	0.155
Netherlands	r = 0	0.238	42.796*	0.000
1850-2001	r = 1	0.019	2.894	0.614
Norway	r = 0	0.292	49.949*	0.000
1865-2001	r = 1	0.032	4.301	0.397
Spain	r = 0	0.137	14.402*	0.020
1908-2001	r = 1	0.009	0.836	0.361
Sweden	r = 0	0.194	43.527*	0.000
1820-2001	r = 1	0.030	5.453	0.265
Switzerland	r = 0	0.213	34.896*	0.001
1876-2001	r = 1	0.046	5.748	0.256

* denotes significance at 5%.

	Null	Eigenvalues	Trace Statistic	*p*-value
Table 3: Life Expectancy (LE) and GDP per capita (GPC)				
Rank Test for the determination of the number of cointegrating vectors				
Australia 1921-2001	r = 0 r = 1	0.410 0.114	50.512* 9.420	0.000 0.060
Belgium 1846-2001	r = 0 r = 1	0.243 0.013	43.659* 1.917	0.000 0.795
Canada 1921-2001	r = 0 r = 1	0.157 0.019	14.454* 1.491	0.012 0.222
Denmark 1835-2001	r = 0 r = 1	0.306 0.027	63.915* 4.384	0.000 0.388
England/Wales 1841-2001	r = 0 r = 1	0.290 0.044	60.878* 7.126	0.000 0.152
Finland 1878-2001	r = 0 r = 1	0.139 0.001	17.913* 0.073	0.003 0.787
France 1899-2001	r = 0 r = 1	0.284 0.036	35.940* 3.574	0.000 0.059
Italy 1872-2001	r = 0 r = 1	0.189 0.015	28.478* 1.928	0.000 0.165
Netherlands 1850-2001	r = 0 r = 1	0.204 0.029	37.874* 4.376	0.000 0.379
Norway 1865-2001	r = 0 r = 1	0.284 0.039	49.400* 5.259	0.000 0.279
Spain 1908-2001	r = 0 r = 1	0.138 0.010	14.535* 0.908	0.020 0.341
Sweden 1820-2001	r = 0 r = 1	0.183 0.019	39.139* 3.331	0.000 0.529
Switzerland 1876-2001	r = 0 r = 1	0.210 0.044	34.144* 5.461	0.001 0.286

* denotes significance at 5%.

Table 4: Life Expectancy (LE) and total GDP				
Long-run coefficients of the VECM				
	ECT = β_1 GDP + β_2 LE		Speed-of-adjustment (α) of the ECT in the equation for:	
	β_1 (GDP) [1]	β_2 (LE)	dGDP	dLE
Australia 1921-2001	1	-8.828* (-3.054)	0.007* (3.472)	0.002* (5.415)
Belgium 1846-2001	1	-4.238* (-11.482)	-0.033* (-7.479)	-0.012* (-2.524)
Canada 1921-2001	1	-9.286* (-13.648)	-0.020* (-2.292)	-0.009* (-6.135)
Denmark 1835-2001	1	-6.452* (-22.009)	-0.043* (-8.919)	-0.005 (-1.200)
England/Wales 1841-2001	1	-2.679* (-2.291)	0.003* (3.977)	0.006* (6.168)
Finland 1878-2001	1	-5.760* (-27.769)	-0.010 (-0.625)	0.088* (4.178)
France 1899-2001	1	-5.920* (-15.645)	-0.055* (-3.085)	0.045* (2.689)
Italy 1872-2001	1	-4.245* (-16.961)	-0.059* (-5.561)	0.010 (0.858)
Netherlands 1850-2001	1	-5.134* (-10.255)	-0.037* (-6.771)	-0.007* (-2.027)
Norway 1865-2001	1	-9.284* (-13.900)	-0.028* (-7.313)	-0.003 (-1.047)
Spain 1908-2001	1	-8.022* (-6.183)	-0.005 (-1.060)	0.016* (3.460)
Sweden 1820-2001	1	-6.518* (-14.562)	-0.025* (-6.449)	-0.000 (-0.085)
Switzerland 1876-2001	1	-3.250* (-3.960)	-0.019* (-4.714)	-0.008* (-3.476)

[1] β coefficients are all normalised on GDP for ease of comparison.
* denotes significance at 5%. *t*-values are given in brackets below each coefficient.

Table 5: Life Expectancy (LE) and GDP per capita (GPC)
Long-run coefficients of the VECM

	ECT = β_1 GPC + β_2 LE		Speed-of-adjustment (α) of the ECT in the equation for:	
	β_1 (GPC) [1]	β_2 (LE)	dGPC	dLE
Australia 1921-2001	1	-4.954* (-4.012)	0.012* (2.381)	0.006* (5.998)
Belgium 1846-2001	1	-3.487* (-8.772)	-0.031* (-6.560)	-0.014* (-2.855)
Canada 1921-2001	1	-6.653* (-13.742)	-0.093* (-3.618)	0.002 (0.590)
Denmark 1835-2001	1	-4.950* (-14.302)	-0.037* (-8.354)	-0.007 (-1.868)
England/Wales 1841-2001	1	-6.437* (-1.963)	-0.001* (-3.842)	-0.002* (-4.935)
Finland 1878-2001	1	-4.743* (-18.756)	-0.024 (-1.504)	0.065* (3.131)
France 1899-2001	1	-4.846* (-15.891)	-0.056* (-2.646)	0.063* (3.016)
Italy 1872-2001	1	-3.520* (-13.750)	-0.058* (-5.429)	-0.009 (0.776)
Netherlands 1850-2001	1	-2.773* (-8.130)	-0.053* (-5.977)	-0.017* (-2.957)
Norway 1865-2001	1	-7.432* (-11.483)	-0.029* (-7.238)	-0.005 (-1.865)
Spain 1908-2001	1	-7.722* (-5.388)	-0.005 (-1.135)	0.015* (3.408)
Sweden 1820-2001	1	-5.024* (-14.702)	-0.033* (-6.280)	-0.002 (-0.231)
Switzerland 1876-2001	1	-2.397* (-4.859)	-0.028* (-4.348)	-0.015* (-3.882)

[1] β coefficients are all normalised on GPC for ease of comparison.
* denotes significance at 5%. *t*-values are given in brackets below each coefficient.

Table 6: Life Expectancy (LE) and total GDP		
Short-run coefficients of the VECM		
	Short-run coefficients significant at 5% in the equation for dGDP	Short-run coefficients significant at 5% in the equation for dLE
Australia 1921-2001	*dGDP*: lags = 1 and 2. *dLE*: none	*dGDP*: lags = 1. *dLE*: lags = 1 and 2.
Belgium 1846-2001	*dGDP*: lags = 2 and 5. *dLE*: none.	*dGDP*: none. *dLE*: lags= 1, 2, 3 and 4.
Canada 1921-2001	*dGDP*: lags =1. *dLE*: none.	*dGDP*: lags = 1, 2 and 4. *dLE*: lags = 1 and 2.
Denmark 1835-2001	*dGDP*: lags = 1 and 2. *dLE*: none.	*dGDP*: none. *dLE*: lags = 1, 2 and 3.
England/Wales 1841-2001	*dGDP*: lags = 1. *dLE*: none.	*dGDP*: lags = 1 and 2. *dLE*: lags = 1, 2, 3, and 4.
Finland 1878-2001	*dGDP*: lags = 1, 2, 3 and 4. *dLE*: none.	*dGDP*: lags= 1. *dLE*: none.
France 1899-2001	*dGDP*: lags = 2 and 5. *dLE*: lags = 3, 4 and 5.	*dGDP*: none. *dLE*: none.
Italy 1872-2001	*dGDP*: none. *dLE*: none.	*dGDP*: lags = 2. *dLE*: lags = 1 and 2.
Netherlands 1850-2001	*dGDP*: lags = 2. *dLE*: lags = 1.	*dGDP*: lags = 1. *dLE*: lags = 1, 2, 3 and 4.
Norway 1865-2001	*dGDP*: lags = 2. *dLE*: lags = 1 and 4.	*dGDP*: lags = 1 and 2. *dLE*: lags = 1, 3 and 4.
Spain 1908-2001	*dGDP*: lags = 1. *dLE*: none.	*dGDP*: lags = 1. *dLE*: lags = 1.
Sweden 1820-2001	*dGDP*: lags= 2. *dLE*: lags = 1 and 2.	*dGDP*: lags = 1. *dLE*: lags = 1, 2, 3 and 4.
Switzerland 1876-2001	*dGDP*: none. *dLE*: none.	*dGDP*: none. *dLE*: lags = 1, 2 and 3.

Table 7: Life Expectancy (LE) and GDP per capita (GPC)		
Short-run coefficients of the VECM		
	Short-run coefficients significant at 5% in the equation for dGPC	Short-run coefficients significant at 5% in the equation for dLE
Australia 1921-2001	*dGPC*: lags = 1 and 2. *dLE*: none	*dGPC*: lags = 1. *dLE*: lags = 1 and 2.
Belgium 1846-2001	*dGPC*: lags = 2 and 5. *dLE*: none.	*dGPC*: none. *dLE*: lags = 1, 2, 3 and 4.
Canada 1921-2001	*dGPC*: lags = 1. *dLE*: none.	*dGPC*: lags = 1and 2. *dLE*: lags = 1 and 2.
Denmark 1835-2001	*dGPC*: lags = 1 and 2. *dLE*: none.	*dGPC*: none. *dLE*: lags = 1, 2, and 3.
England/Wales 1841-2001	*dGPC*: lags = 1. *dLE*: none.	*dGPC*: lags= 1 and 2. *dLE*: lags = 1, 2, and 3.
Finland 1878-2001	*dGPC*: lags = 1, 2, 3, and 4. *dLE*: lags = 1.	*dGPC*: lags = 1. *dLE*: lags = 1.
France 1899-2001	*dGPC*: lags = 2 and 5. *dLE*: lags = 3, 4 and 5.	*dGPC*: none. *dLE*: none.
Italy 1872-2001	*dGPC*: none. *dLE*: none.	*dGPC*: lags = 2. *dLE*: lags = 1 and 2.
Netherlands 1850-2001	*dGPC*: lags = 2. *dLE*: lags = 1.	*dGPC*: lags = 1. *dLE*: lags = 1, 2, 3 and 4.
Norway 1865-2001	*dGPC*: lags = 2. *dLE*: lags = 1 and 4.	*dGPC*: lags = 1 and 2. *dLE*: lags = 1, 3 and 4.
Spain 1908-2001	*dGPC*: lags = 1. *dLE*: none.	*dGPC*: lags = 1. *dLE*: lags = 1.
Sweden 1820-2001	*dGPC*: lags = 2. *dLE*: lags = 1 and 2.	*dGPC*: lags = 1. *dLE*: lags = 1, 2, 3 and 4.
Switzerland 1876-2001	*dGPC*: none. *dLE*: none.	*dGPC*: none. *dLE*: lags = 1, 2 and 3.