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METHODS

Diffusion of innovations in health care: Does the structural context determine its direction?

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Objectives: The aim of this study was to present and illustrate an instrument to measure the level of innovation at country level.
Methods: The data used are the Organisation for Economic Co-operation and Development (OECD) health data 2009, in particular the information on use of medical technology. Two composite scales expressing a relative level of adoption of innovations in health care are regressed, using multilevel regression analysis, on country characteristics. The country characteristics are selected as proxies on availability or scarcity of resources in a country. We expect that scarcity will promote adoption of innovations that enhance efficiency, and that availability of resources will promote advanced, expensive innovations.
Results: Two scales were constructed. One scale indicates the use of efficiency-enhancing innovations (day case treatment), and the other scale indicates availability of advanced technical innovations. The application of day case treatment is significantly associated with education level (+), the ratio of people aged 15–64 versus younger and older people (+) and the number of hospital beds (−). Availability of advanced medical devices are associated with the expenditure on health (+), demographic dependency (−), number of hospital beds (+), and the annual reduction of hospital beds (−).
Conclusions: Diffusion of innovations is influenced by characteristics of the country and of the healthcare system; fewer resources encourage diffusion of innovations that enhance efficiency and more resources encourage diffusion of complex, expensive devices. This indicates that decisions by healthcare professionals on which innovation to adopt is embedded in a context that is influenced and shaped by the availability of resources on macro level.

Keywords: Diffusion of innovations, Macro-level conditions, Quantitative measurements, International comparison

Diffusion of innovations depends on the characteristics of the “receiving” (social) system (11). Although awareness of novelties in the healthcare systems of the modern Western world travels fast, important differences between countries can be observed in the degree and manner in which, for instance, new surgical procedures, diagnostic tools, and forms of healthcare organization are adopted. One factor that is crucial in the introduction of innovations is, of course, the available budget and how it is affected. It is well known and accepted that innovation is a major driver of increases in medical spending (7), but the health benefits to the population are generally considered to outweigh the higher costs (3;4). Moreover, efficiency gains may even have a favorable impact on overall costs.

Studying the diffusion of particular innovations in a (sector) of society and comparing different societies brings to light differences in their acceptance of novelties. However, knowledge as to how and why the diffusion of innovations differs between systems is still scarce. Research focusing on macroeconomic aspects and regulations (e.g., 1) has indicated that there is a relation between gross domestic product (GDP) and the introduction of various forms of transplanting hematopoietic stem cells (5). The spread of the use of various scanning technologies has been found to be associated with healthcare expenditure and GDP (6). Oh and others (9) have shown that the diffusion of computed tomography (CT) and magnetic resonance imaging (MRI) devices is affected by purchasing power and by payment structures in the healthcare system of a country.

In this study, we extend this line of research. We start from the expectation that, when resources are abundant, complex and costly innovations will easily find their way into regular health care; and that scarcity of resources leads to the adoption of innovations that enhance efficient healthcare delivery.

To be able to study the diffusion of innovations at the level of countries, it is necessary to develop appropriate research tools. Thus, we first describe a way of measuring innovations in health care at a country level. Then, we will give an illustration of how this can be used to link the diffusion of innovations of a country to macroeconomic and sociological country characteristics: we will investigate whether country characteristics can explain differences in the observed country differences in innovativeness.

METHODS

Measures of Diffusion of Innovations in Healthcare Data

We propose an innovation score that is computed from country data provided by the yearly Organisation for Economic Co-operation and Development (OECD) reports (OECD Health Data [2009]). These reports contain aggregate data on innovative medical technology (mainly medical equipment and procedures) used by the various countries. The innovation score ranks countries on a scale of how widely they have adopted these innovations, or its "innovativeness."

The relevant data sets of the OECD contain aggregate numbers per country of the following items: computed tomography (CAT) scanners (number per million population), MRI units (number per million population), lithotripters (number per million population), and percentage cholecystectomies performed by laparoscope of total number of cholecystectomies, percentage of cataract operations performed as day cases; percentage of inguinal and femoral hernia operations performed as day cases; and percentage tonsillectomies performed as day cases.

Briefly, these items were chosen as examples of medical innovation, either because they greatly improve noninvasive diagnostic possibilities, or because they represent new, less invasive, more convenient and cheaper operative interventions. This will be further explained in the discussion. We used data from all the OECD countries, covering the years 1996 through 2007.

Construction of Two Diffusion of Innovation Scales

A basic property of the level of "innovativeness" of a country is that it may differ over time, and that it is relative to that of other countries. A measuring tool should capture this time dependency and the essence of the relational dimension. The scale we propose, therefore, aims to express in a quantitative and time-dependent manner the relative level of adoption of applications in health care that a country uses.

First, for each of these types of innovation a relative score per country was computed by dividing the relevant value indicator (e.g., percentage of day-case cataract surgeries, from total cataract surgery) by the sum of the values for that indicator of all countries together. This was done for every year for which data were available, resulting in an ordinal rank-score per country, per year, and per innovation. A higher score represents a higher degree of adoption of the relevant innovation. The formula for calculating the score is displayed in the appendix.

We conducted principal component analyses to study possible clustering in the dataset of the ordinal rank scores of the score of the innovations. Supplementary Table 1 (which can be viewed online at www.journals.cambridge.org/thc2010028) shows the rotated component matrix. After seven iterations two components were extracted. The components correlate with −.20 with each other. The first component shows that the 3 day-case items (cataract, inguinal or femoral hernia, and tonsillectomy) load well. These procedures are as such not too innovative, but the fact that they are increasingly performed as day cases makes them more innovative. The innovative aspects of these developments centre on the surgery itself: anesthetics and the logistic of the operation. These "logistical novelties" have in common that they have decreased the time that patients need to spend in hospital for the surgery. They increase the efficiency of care. The other four items load better on the second component from the day-case scales. We, therefore, distinguished a second cluster of innovations: advanced medical devices, being MRI, CT, lithotripters, and

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laparoscopic cholecystectomies. The first three are based on availability per million population, the fourth is the percentage laparoscopic procedures of total procedures. These technological innovations have in common that they involve expensive, complex devices that need trained staff to operate.

Second, reliability analysis (2) was used to assess how various (sub)scales (of individual innovations) fit into one overall scale. The aim was to construct an aggregate scale combining the separate item-scores into one score expressing the latent construct combined scale was sought after to construct a scale that expresses a latent construct: a country's innovativeness.

Reliability analysis confirmed the identification of two scales. The mean Cronbach's alpha of the "complex devices" scale was .72 with a yearly variation between .85 and .55. This means that over the complete data set, the scale works well, especially in the beginning and middle of the observed period.

It should be noted that there is a correlation between the use of CT scans and MRIs, due to the fact that there is overlap in the indications for which they are used. Thus, for some indications and settings, MRI has largely replaced MRI. However, it is also the case that MRI has major indications of its own, especially when visualizing soft tissue structures is essential, while CT scanning remains the preferred option when visualizing bony structures, MRI is too cumbersome, or when costs are an obstacle. Moreover, with MRI as competitor, also CT imaging continues to evolve and find new applications, such as CT coronary angiography. Thus, in these respects, MRI and CT imaging are complements rather than "perfect substitute goods," to use the terminology of economic theory.

The "day-cases scale" consists of three items: percentage of day cases (of total cases) for cataract, tonsillectomy, and for inguinal or femoral hernia. The mean Cronbach's alpha for this scale was .79 aggregated over all years with a yearly variation between .78 and .85, indicating that the items scale well in all years.

Supplementary Figures 1 and 2 (which can be viewed online at www.journals.cambridge.org/thc2010028) illustrate some of the characteristics of this score, when studying the overall pattern of the data and not so much the individual scores per country. These figures represent for each country the percentage of day case treatments for inguinal and femoral hernia's and the scores on the day cases scale respectively. Note the difference in the slope of the development over time (the thicker line). Where there is an increase in the percentages (Supplementary Figure 1), this increase is not seen in the day-cases scale (Supplementary Figure 2). This is to show that the measurement of innovation solely represents the relative position of a country at any given point in time, as compared to the position of all other countries. The absolute increase in use of the innovations disappears in this score.

Selection of Country Level Characteristics

We hypothesized that availability of resources in a country will affect which innovations healthcare professionals will adopt. Economic theory distinguishes two major categories of resources: human capital and financial capital. In the context of health care, we interpreted this as, respectively, "skills" and "money."

The first way to measure human capital is by the criterion of the highest educational level attained, expressed as the percentage of people between 25 and 64 years old who have completed the highest levels of schooling according to the International Standard Classification of Education (ISCED) system (8). The ISCED was designed by United Nations Educational, Scientific and Cultural Organization (UNESCO) as an instrument to make educational achievements comparable between countries.

A second parameter assessing human capital is the demographic dependency ratio, by which we mean the ratio of citizens aged between 15 and 64 years, versus those younger than 15 or older than 64. This ratio reflects both the level of available human capital in a country and the need for health care. People use most healthcare services in the beginning and the end of their lives. So, the less favorable this ratio, the more need for health care, and the less human capital a country has.

As far as structural factors of the healthcare system which may affect the tendency to implement innovations is concerned, we selected two readily available measures: the number of beds per 1,000 inhabitants, and the percentage of available hospital beds (per 1,000 inhabitants) in a particular year compared with the year before. We expect that the fewer beds there are, the more innovations that are aimed at efficiency will be adopted in a country.

As measure of financial capital we chose GDP per 1,000 inhabitants. We initially also considered expenditure on health as percentage of GDP, but that measure turned out to be highly correlated with GDP per 1,000, causing multicollinearity problems. We chose to just use GDP per 1,000 inhabitants. We expect that, when there is less money available for health care, more innovations aimed at efficiency will be adopted and fewer complex innovations

Statistical Analyses

The data are, by the nature of the analysis, clustered in place (countries) and time (year of observations). To adequately take into account this clustering, multilevel regression analysis needs to be used (10;12). We distinguished two levels: the higher level is country, the lower level consists of observations of countries in subsequent years.

The presence and importance of a trend (in time) was studied using the intra-class correlations for equations with and without a trend variable. It showed that most variance is found between countries, and there is little variance between

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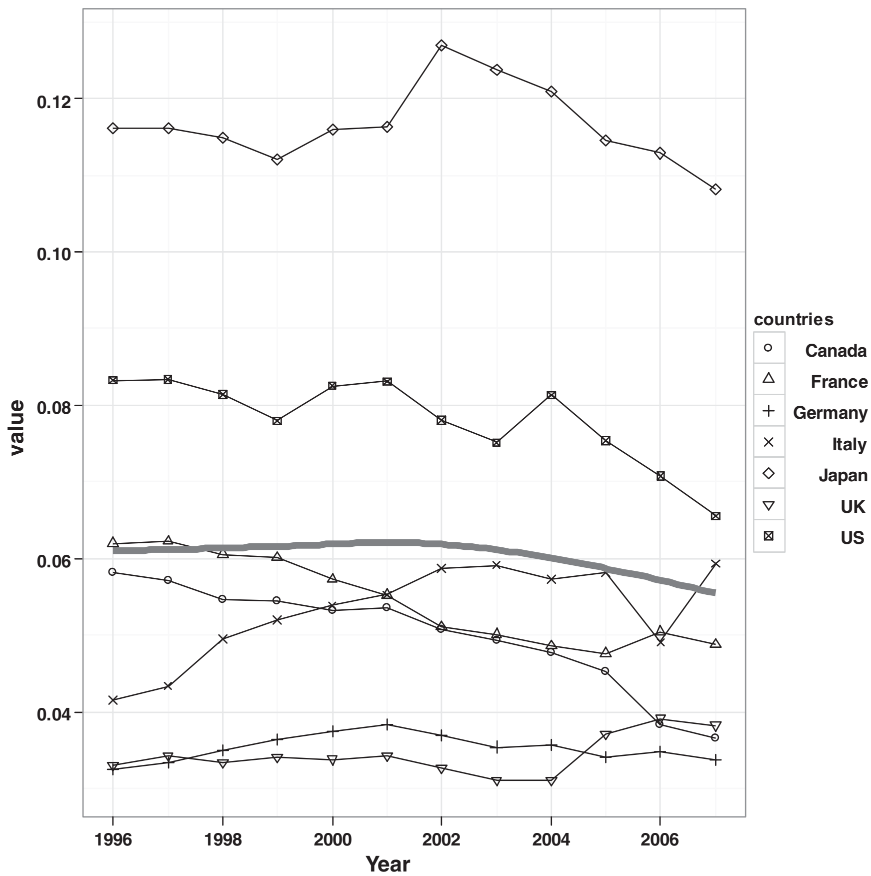

Figure 1. Example scores of countries on complex-devices scale, selected countries. The thick line shows the mean score.

the years. Therefore, no trend variable was included in the final analyses.

RESULTS

Descriptive Results

In Figure 1 and Supplementary Figure 2, the relative positions of the selected countries on the two scales are shown. For reasons of readability, not all countries are included. The scale of day-cases (Supplementary Figure 2) shows that Canada has had relatively the highest score, and that this advantage is decreasing. For the scale on complex devices (Figure 1), we see that Japan has had the highest score for some years now, and slowly starts to lose its relative advantage. Table 1 shows the mean and standard deviations of variables included in the subsequent analyses.

Associations of Country Resources and Innovation Measures

The second and third columns of Table 2 show the resulting model of the multilevel regression analyses, predicting the score on the "day case treatment" scale as a function of the selected country characteristics. The difference of variances on country level between the null model and the full model indicates that approximately 9 percent of the variance on country level is explained by the model. The variance on the lowest level drops from 72.95 to 32.13, indicating that more than half of the variance on that level is explained by the model.

The application of day case treatment is significantly associated with education level (+), demographic dependency (+), and the number of hospital beds (−).

The fourth and fifth columns of Table 2 show the results for the complex technological innovations. Here we see that the variance between the null model and the full model differs approximately 25 percent. On the unit-level, the variance

Table 1. Means and SDs of Variables in the Multilevel Regression Equation

Variable name	Mean	SD
Complex medical devises	0.04	0.03
Application of day case treatment	0.05	0.03
GDP per capita (*1000)	25.48	9.50
% highest level of education	42.82	16.43
Demographic dependency	49.23	4.45
Number of hospital beds per 1000 pop	5.78	2.64
Care beds, as % of previous year	0.99	0.03

GDP, gross domestic product.

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Table 2. Multilevel Regression Analysis Prediction Innovation Scales

		Day cases B (SE)		Complex B (SE)
GDP per capita		−0.18		0.31**
		(0.16)		(0.07)
% highest level education		0.79**		0.06
		(0.15)		(0.08)
Demographic dependency		2.89**		−0.77**
		(0.37)		(0.18)
Number of hospital beds per 1000 pop		−7.43**		7.40**
		(1.82)		(0.61)
Acute care beds, % of previous year		−5.15		−33.40**
		(19.36)		(11.68)
Constant	53.72**	−75.26**	42.66**	59.67**
	(6.76)	(32.52)	(4.63)	(15.59)
Variance country level	905.37**	820.40**	640.00**	495.97**
	(30.09)	(28.64)	(25.30)	(22.27)
Variance unit level (year-country)	72.95**	32.12**	28.81**	16.93**
	(8.54)	(5.67)	(5.36)	(4.11)
−2 log likelihood	1651.0	1213.0	2329.0	1788.6

**= $p < .01$.
GDP, gross domestic product.

drops from 28.81 to 16.93, which indicates that the model explains approximately 40 percent of the variance on the lower level. In this model, we see significant associations of GDP per capita, (+), the dependency ratio (−), number of hospital beds (+), and the annual reduction in the number of hospital beds (−).

CONCLUSIONS AND DISCUSSION

To be able to study the variation between countries in the adoption of medical innovations we developed two scales that measure the relative score of countries of their diffusion of innovations in health care. We showed how the tool can be used to assess the manner in which the tendency to adopt innovations depends on macro-economic and sociological characteristics of a country.

Departing from several specific innovations for which data were readily available, per item score was calculated for each year. Principal component analysis resulted in two components, which identified the scales. Subsequently, reliability analysis was used to confirm the "subscales" representing underlying dimensions. The choice of items was determined by theoretical considerations and by the availability of data. The data were taken over from the OECD health data set of 2009 covering twenty-six countries over the period from 1996 to 2007.

The analyses show some support for the expectation that health professionals will adopt more complex innovations when budgetary condition allow this and will adopt innovations that generate more efficient care when the budget is limited. We found significant opposing effects of demographic dependency and the available number of hospital beds. Concerning demographic dependency, we see that the greater the share of citizens in a country older than 64 or younger than 15, the more frequent is day-case treatment, while fewer complex medical devices are available. The number of available hospital beds is negatively associated with the share of day-case treatment, and positively with the availability of complex medical devices.

From our analysis it appears that, indeed, macroeconomic factors constitute an important force in determining the adoption of innovations.

These results pertain mainly to the predictor variables with which we intended to estimate scarcity of resources (i.e., demographic dependency and (reduction in) hospital beds). With regard to the remaining variables, namely GDP and education, we find some results in the expected direction, but weaker. We find that GDP is positively associated with the availability of advanced medical devices, but no association was found with the share of day-case treatment. We also find a positive association with education and the share of day-case treatment, but not with availability of advanced medical devices.

These associations are cross-sectional. One predictor that includes a time lag is the year on year reduction (or increase) in hospital beds, expressed as the percentage of hospital beds compared with the previous year. For complex medical innovations, we see a negative association, indicating that the larger the decrease of hospital beds in a country, the more complex medical devices are available. This finding seems difficult to interpret, as we also found a positive cross-sectional association with the numbers of beds. It could indicate that the availability of sophisticated medical equipment in the long run prevents unnecessary hospital admissions and, therefore, tends to lead to a progressive reduction in the numbers of beds. Or, alternatively, reductions in the

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numbers of hospital beds and the availability of technologically advanced apparatus are both signs of a more mature (high-level) medical system, with fewer hospital admissions and/or shorter hospital stays. Especially a process of ongoing reductions in the number of beds could signify greater efficiency achieved by the use of technology, although it could also mean forced cuttings in spending.

The data were not gathered to test the hypothesis of this study. As a consequence, they were not in all respects perfectly suited for the analysis. One of the problems is that the number of variables available for analysis that are indicators of the use or the availability of newer medical techniques is limited and represents a selection determined within a particular context and meeting particular requirements. As a consequence, the innovation scales do not represent the development of the most recent innovations. It could be argued that the items used to construct the scales of this study, are no longer innovations, and that every decent healthcare system should have those techniques available in the time under study. However, even if this is admitted, it is still the case that the degree to which the items included in the scales are used and widely available differs considerably between countries. Thus assessing the differences in the use of these "no-longer-new-but-still-quite-recent" techniques still gives insights into systemic differences in the adoption of innovations in health care. In fact, studying such patterns of diffusion of innovations requires a horizon of observation that is sufficiently long to be able to discern patterns.

The adoption of innovations in health care takes place on the level of the professional, the doctors and nurses, and that of the management of hospitals and other parties such as healthcare insurers or administrators, patient advocacy groups, or private investors willing to finance health care. The problems that professionals encounter require innovative solutions, and they will be a decisive force in deciding whether or not to adopt an innovation. However, the context (societal structures and characteristics, including the macroeconomic environment) in which the professionals operate may also strongly affect the problems they face and, therefore, the decisions that are made. This framework differs per country and this study supports the notion that country differences affect the direction of innovations.

SUPPLEMENTARY MATERIAL

Supplementary Table 1
Supplementary Figure 1
Supplementary Figure 2
www.journals.cambridge.org/thc2010028

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CONFLICT OF INTEREST

All authors report having no potential conflicts of interest.

APPENDIX

Computation of score of diffusion of innovations of a country l on moment t

$$Inno_{l,t} = \frac{\sum_{i=1}^{m} A_{l,t}}{\sum_{i=1}^{m}\sum_{l=1}^{n} A_t}$$

Where A is the number of adopters who adopted the innovation i, m is the number of innovations included, l is the actor, n is the number of actors (e.g., countries) included in the analysis.

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