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Machines that go 'ping': medical technology and health expenditures in OECD countries

OBSTETRICIAN: More apparatus, please, nurse: the E.E.G., the B.P. monitor, and the A.V.V.
NURSE: Yes. Certainly, Doctor.
DOCTOR SPENSER: And, uh, get the machine that goes 'ping'.
OBSTETRICIAN: And get the most expensive machine, in case the administrator comes.

Monty Python, *The Meaning of Life*

January 2013

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Abstract - While rising health care expenditures as a percentage of national income is a well-known and widely documented feature across the industrialized world, it has proved difficult to quantify the effects of the underlying cost drivers. The main difficulty is to find suitable proxies to measure medical technological innovation, which is believed to be a major determinant of steadily increasing health spending. This paper's main contribution is the use of data on approved medical devices and drugs to proxy for medical technological progress. The effects of these variables on total real per capita health spending are estimated using a panel model for 18 OECD countries covering the period 1981-2009. The results confirm the substantial cost-increasing effect of medical technology, which may account for at least 50% of the explained historical growth of spending. Excluding the approval variables causes a significant upward bias of the estimated income elasticity of health spending and negatively affects some model specification tests. Despite the overall net positive effect of technology, the effect of two subgroups of approvals on expenditure is significantly negative. These subgroups can be thought of as representing 'incremental medical innovation', while the positive effects are related to radically innovative pharmaceutical products and devices. The results are consistent with those reported in other studies which suggest that some new products, despite their high price when they are introduced, can ultimately save money by reducing spending on other medical interventions.

Abstract - Terwijl het stijgende aandeel van de gezondheidsuitgaven als procent van het nationaal inkomen een welbekend en uitvoerig beschreven fenomeen is in de geïndustrialiseerde wereld, is het moeilijk om de effecten van de onderliggende kostendrijvers te kwantificeren. De grootste moeilijkheid is het vinden van geschikte proxies om de medisch-technologische innovatie te meten. Die laatste wordt beschouwd als een belangrijke determinant van de steeds toenemende gezondheidsuitgaven. De belangrijkste bijdrage van deze paper is het gebruik van data over goedgekeurde medische apparatuur en geneesmiddelen als indicatie voor de medisch-technologische vooruitgang. De effecten van deze variabelen op de totale reële gezondheidsuitgaven per hoofd worden geraamd aan de hand van een panelmodel voor 18 OESO-landen dat betrekking heeft op de periode 1981-2009. De resultaten bevestigen het aanzienlijk kostenverhogend effect van de medische technologie die minstens 50 % van de historische uitgavengroei kan verklaren. Het weglaten van de goedkeuringsvariabelen leidt tot een aanzienlijke opwaartse vertekening van de geraamde inkomenselasticiteit van de gezondheidsuitgaven en heeft een negatief effect op sommige modelspecificatietesten. Ondanks het totale positieve netto-effect van de technologie, is het effect van twee subgroepen van goedkeuringsvariabelen op de uitgaven duidelijk negatief. Die subgroepen kunnen als representatief voor 'incrementele medische innovatie' worden beschouwd, terwijl de positieve effecten betrekking hebben op 'radicaal' innovatieve farmaceutische producten en apparatuur. De resultaten zijn coherent met die uit andere studies die suggereren dat sommige nieuwe producten, ondanks hun hoge introductieprijs, uiteindelijk kostenbesparend kunnen zijn voor andere medische ingrepen.

Abstract - Alors que l'augmentation de la part des dépenses de soins de santé dans le revenu national des pays industrialisés est un phénomène bien connu et largement documenté, l'effet des facteurs de coût sous-jacents reste difficilement quantifiable. La principale difficulté est d'identifier des proxies pour mesurer l'innovation technologique médicale et ainsi tester l'hypothèse que celle-ci constituerait un déterminant majeur de l'augmentation continue des dépenses de soins de santé. L'originalité de cette étude consiste à utiliser des données sur les agréments officiels d'équipements médicaux et de produits pharmaceutiques comme proxy pour le progrès technologique médical. Les effets de ces variables sur les dépenses totales réelles de soins de santé par tête sont estimés par le biais d'un modèle appliqué à un panel de 18 pays de l'OCDE sur la période 1981-2009. Les résultats confirment que la technologie médicale contribue largement à l'accroissement des coûts et pourrait expliquer au moins 50% de la croissance historique des dépenses. Exclure ces variables implique un important biais à la hausse de l'élasticité-revenu des dépenses de soins de santé et affecte négativement certains tests de spécification du modèle. Malgré l'effet global positif net de la technologie sur les dépenses, l'effet de deux sous-groupes d'agréments est clairement négatif. Ces sous-groupes peuvent être vus comme représentatifs d'innovations médicales « incrémentales », tandis que les effets positifs sont générés par des produits pharmaceutiques et des équipements médiaux radicalement innovants. Ces résultats sont compatibles avec ceux d'autres études qui montrent que certains nouveaux produits peuvent contribuer - en dépit d'un prix élevé lors de leur lancement - à réaliser des économies puisqu'ils induisent une baisse des dépenses pour d'autres interventions médicales

Jel Classification - C23, H51, I10

Keywords - health care expenditures, income elasticity, ageing, medical technology

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1. Introduction

The rising share of health care spending in GDP across countries over the past decades has been matched by the proliferation of models that try to explain the phenomenon. These models differ in terms of the level of aggregation of the data used, their geographical scope, the explanatory variables used, their specification and the estimation methods. Perhaps not surprisingly, the results and conclusions also vary wildly, both in terms of the relevant determinants and of the magnitude of their effects on health expenditures. The estimated income elasticity, for instance, ranges from well below to well above unity, depending on the study. One of the key factors behind these differences, apart from the different countries and time periods studied, is the inclusion of a time trend as a proxy for medical technological progress. Ever since Weisbrod's seminal paper (Weisbrod 1991), and maybe even more after Newhouse's conjecture (Newhouse 1992), medical technology is considered one of the key drivers of rising health expenditure, possibly accounting for as much as 50 percent of the post-war growth in health spending [1]. However, while there is a wide consensus among health economists about the impact of medical technology on costs, its effect has proven very difficult to quantify. This is mainly due to the difficulty of measuring technological progress, or finding suitable proxy variables.

This paper reassesses the impact of medical technology on aggregate health expenditures in 18 OECD countries. Its main contribution consists of introducing a new set of indicators of medical technological progress, based on the number of approved medical devices and pharmaceutical products. These variables are divided into two subgroups, related to the type of product and the corresponding approval procedure. The effects of the four technology indicators on total real per capita health spending are estimated using a panel econometric model.

The paper is organized as follows. Section 2 gives a short overview of the literature on health expenditure modeling and summarizes the debate on the contribution of the main conjectured cost drivers, including medical technology. Section 3 discusses the problems of measuring medical innovation. Section 4 describes the data used in this study. Section 5 presents the model and tests the order of integration of its variables. Section 6 discusses the estimation results and assesses the contribution of medical technological progress and the other model variables to the historical growth of aggregate health spending. Section 7 concludes.

[1] This figure was revised downward in a recent update of the Newhouse study. See Smith et al. 2009.

2. Health expenditures: models and determinants

The empirical literature on health expenditure determinants is abundant, and several overview articles are available (see Gerdtham & Jonsson 2000, Chernew & Newhouse 2012). Several criteria can be used to categorize the many contributions, and one of them is the level of aggregation of the data used. Micro studies typically use two-part models to explain individual health care use and spending. In this strand of the literature, an ongoing debate focuses on the relative importance of age versus proximity to death (the 'red herring' hypothesis) in explaining the age profile of spending (see Werblow et al. 2007). Empirical macro models tend to rely on national time series or international panel data to explain the determinants of total (public) health expenditures. The determinants vary between studies, but (real per capita) income, the age composition of the population and (proxies of) medical technological progress are usually included (see also the recent review by Martín et al. 2011). Results appear to depend on the time period and countries included in the study, and in particular on the measure of medical technology used. Some studies include proxies that reflect specific high-tech applications, such as the number of MRI scanners per thousand of population. However, since measures like these do not necessarily reflect medical technological progress in general, many authors use a time trend as a generic technology proxy. Unfortunately, a trend variable may capture the effects of all kinds of non-stationary variables and its incorporation severely affects the parameter estimates of the other explanatory variables, in particular income (Roberts 1999). As a result, the empirical results obtained with models that contain trends are difficult to interpret. Regardless of the inclusion of technology proxies, the debate on the income elasticity of health spending is far from settled. Even the most recent studies report very different estimates: Baltagi & Moscone (2010) conclude that health care is a necessity rather than a luxury in the OECD, with income elasticities ranging between 0.45 and 0.87 depending on the model specification. Woodward & Wang (2011) on the other hand, report a stable long-run relationship between per capita health spending and income in the U.S., with an implied income elasticity of 1.39. Both studies lack a technology variable, based on the argument that technology is endogenous because it is 'enabled' by income growth.

As regards the choice between heterogeneous (country-specific) time series or homogeneous panel data models, Baltagi & Griffin (1997) conclude that the efficiency gains from pooling more than offset the bias due to inter-country differences. This result justifies a panel model approach despite the fact that pooling restrictions are unlikely to be valid (see e.g. Herwartz & Theilen 2003). Panel data models entail a particular additional problem, however, in that they require the national health care spending and income data to be converted to a common currency in constant prices. The standard way to do this is to use US dollar purchasing power conversion factors ($PPP). Unfortunately, the choice of the conversion factor (exchange rates, PPP's for GDP, PPP's for health care) influences the results and may bias the estimated model parameter (Gerdtham & Jonsson 2000).

Following the developments in non-stationary time series econometrics, many authors have gone to great lengths examining the unit root properties of health expenditures and GDP, both at the country level and in panels of countries. In general, it is concluded that both variables contain a unit root in levels, but are stationary after differencing (see Herwartz & Theilen 2003). However, some studies reject the unit root hypothesis in tests that allow for structural breaks in the series (see Jewell et al. 2003

and Narayan 2006). Of course, in order to determine whether or not health spending is cointegrated with its determinants requires the specification of a 'complete' model, in which the order of integration of all variables matters.

An alternative approach to quantifying the effect of medical technology on health spending was proposed by Newhouse (1992), who relied on Solow's growth accounting model to estimate the contribution of technology to the post-war growth of U.S. health expenditures. Just as in macroeconomic analyses, the effects of 'known' determinants on health care spending are subtracted from total health expenditure growth, and the residual growth is attributed to technological progress. The residual actually captures the effects of all omitted variables and the errors in the attributed effects of the included variables. In the Newhouse model, for instance, the latter include a unit elasticity of both income and the age composition of the population. Despite this limitation, Newhouse's paper has been very influential: it almost certainly helped shape the current consensus among health economists that technology has played a dominant part in the steadily increasing share of health spending as a percentage of GDP in the post-war industrial world.

One of the few attempts to test the Newhouse claim econometrically is due to Okunade & Murthy (2002), who use economy-wide and medical R&D spending as proxies for (medical) technical progress. The authors find a stable long-run relationship between real per capita health care expenditure, per capita real income and R&D expenditures. Somewhat surprisingly, they find that total R&D spending has a stronger and more significant effect than the more specific medical R&D variable. More seriously, the long-run relationship between R&D spending and health expenditure is contemporaneous, which does not seem plausible given the (very) long lags between R&D efforts and the resulting marketable products, if any.

Pammolli et al. (2005) list the different methodologies that have been used to assess the link between medical technology and healthcare expenditures:

- Econometric analysis of the determinants of healthcare expenditures, using some proxy of medical technology.
- Residual approach, estimating the impact of other determinants than technology (e.g., income and demographics) and attributing the residual to technology.
- Descriptive analysis of data.
- Case studies on the cost of specific technologies.
- Surveys and interviews with experts.

All these methodologies have drawbacks. The residual approach will provide a biased estimate of the impact of technology if the relationship between health expenditures and the other determinants is not correctly specified. Descriptive analysis may result in spurious relationships and results from case studies are difficult to generalize. Surveys and interviews may be biased by the subjective views of the experts that are being interviewed. The authors argue that the econometric analysis including all potential determinants in principle provides the most rigorous assessment of both the significance and magnitude of each individual determinant. The main problem with this approach is that due to the lack

of a measure for technological change, some imperfect proxy is used. The variables used to proxy medical technology will be discussed more in detail in the next section. Although some case studies provide evidence of the cost-reducing effects of specific technologies, Pammolli et al. (2005) conclude that empirical studies tend to point at medical technology and innovation as the main driver of rising health expenditures. While this may be true for medical technology in general, several studies paint a more balanced picture, especially regarding the role of pharmaceuticals. For example, Cïvan & Köksal (2009) analyze the impact of new drugs on health spending. They conclude that, despite the fact that newer drugs are usually more expensive than their predecessors, they still lower overall health spending because they lower the demand for other types of medical services. A key point is that the newer drugs are not cost-saving themselves (since they are more expensive), but that they result in a net overall savings. Similarly, Lichtenberg (2006) studied the effect of new ('vintage') drug utilization on hospital discharges, and found a net cost-reducing effect. Encinosa et al. (2010) also report cost savings from averted hospitalizations which more than offset increased drug spending resulting from increased adherence to diabetes drugs. These studies suggest that, even if new medical technology is expensive, it may lead to cost savings resulting from averted or reduced usage of other medical interventions. The result may even be a net cost reduction, especially in the case of pharmaceuticals. If these results are robust, they cast doubt on the meaning of the cost-increasing effects of medical technological progress estimated by means of trends in time series models.

The next section provides a detailed review of the literature on the measurement of medical technological innovation and its impact on health care spending.

3. Measuring medical technological innovation

Technological progress and innovation are generally considered to be the main drivers of economic growth in advanced economies. In addition, medical technology is specifically credited for raising the expectancy and quality of life (e.g. Lichtenberg 2012). At the same time, it is also commonly considered to explain the surge in health expenditures in recent decades. Whether, or to what extent, this is really the case, is difficult to assess empirically for a number of reasons. For example, Neumann & Weinstein (1991) conclude that the lack of a clear-cut definition of medical technology hampers the assessment of its impact on health expenditures. Definitions commonly include drugs, devices, surgical procedures and organizational support systems. They argue that measuring the contribution to medical costs of each item separately is close to impossible, even if the most important innovations could be listed. The effect of technology on expenditures is not restricted to the purchase price. The introduction of new devices or machines may imply substantial additional costs in terms of operation, supervision, training, insurance, supplies and space or the increased use of additional tests (e.g., to confirm diagnosis based on new imaging devices). However, medical innovation need not necessarily result in higher costs as new drugs or devices may be less expensive to administer or avoid other diagnostic procedures (Neumann & Weinstein 1991). An additional complication is that drugs or devices that are cost effective in one clinical situation can be rather costly in other situations. Medical technology may diffuse into domains where the benefit in terms of health is outweighed by high additional costs. The authors evoke a 'Peter Principle' in health care in stating that medical technology will expand into applications that are cost ineffective.[2]

In the studies surveyed by Pammolli et al. (2005), medical technology is proxied by a time trend (Blomqvist & Carter 1997; Zweifel et al. 1999; Di Matteo 2005), R&D expenditures (Okunade & Murthy 2002; Peden & Freeland 1995) or insurance coverage (Peden & Freeland 1998). Baker et al. (2003) considered the impact of infrastructure-intensive capabilities on US health care spending. They considered technologies used for diagnostic imaging (MRI and CT units); the treatment of cardiac patients (e.g., hospitals with catheterization facilities and cardiac intensive care units); cancer treatment (e.g., hospitals with PET scanners) and newborns (neonatal intensive care units). The criterion for choosing these specific applications was the high investment cost or the use for patients with expensive conditions. The analysis did not involve multivariate estimation but was based on the correlation between medical technology and health care costs. There were indications of technologies that appear to complement one another (e.g., MRI and CT scans) as well as substitute for one another (e.g., percutaneous transluminal coronary angioplasty and coronary bypass graft). For most technologies that were considered there appears to be a strong correlation with total spending, with more mixed evidence for spending under Medicare than for beneficiaries covered by a commercial plan. The authors pointed out the high correlation between the different specific medical technologies which may bias the assessment of the impact on health care costs. From a policy perspective, they concluded that an unequivocal approach to the adoption of medical technology is not warranted and that the most effective policy would consist in promoting some specific technologies but to discourage other applications. Koenig et al. (2003) esti-

[2] Beever & Karbe (2003) also point out the duplication of medical procedures (e.g., combining CT with a PET scan) and the use of medical technologies with large benefits in some cases in cost ineffective situations (e.g., implantable cardioverter defibrillators).

mated the impact of specific medical technologies on per capita health expenditures for physician services in the US. In their multivariate analysis a large number of potential determinants were introduced (e.g., demographics, health status, insurance and benefit program). For medical technology the following variables were considered: Percent of total surgeries performed on an outpatient basis; Percent of hospitals with CT scanner, MRI, PET scanner, SPECT[3] scanner, diagnostic radioisotope services; Percent of hospitals offering burn care and cardiac catheterization; Percent of hospitals with organ transplant capabilities and the number of academic health centers. For the period 1990-2000, the authors estimated that 42% of growth in nominal per capita physician expenditures could be explained by price inflation. General economic and demographic variables contributed 17% and physician supply and provider structure 12%. The variables on medical technology and treatment patterns only explained 11%. Hay (2003) estimated the impact of specific medical technologies on hospital inpatient expenditures, using data from US states for the period 1998-2001. The variables used in the multivariate regression for medical technology were similar to Koenig et al. (2003). Economic variables (e.g. growth in per capita income) again explained most of the growth in inpatient costs, followed by hospital technology. Inpatient costs were higher in US States with more hospitals that belong to academic health centers or with more spectral scanners or burn care facilities. On the other hand, more diagnostic radioisotope facilities and MRI equipment tend to be correlated with lower state-level inpatient costs. Hay also pointed out the strong correlation between many technology variables which hampers the unbiased estimation of the effects of individual technologies. Using the same variables as Koenig et al. (2003) and Hay (2003), Hearle et al. (2003) estimated that medical technology accounted for 7% of growth in outpatient health expenditures over the period 1996-1999, making it the least substantial cost driver of the different determinants that were considered. Blank & Vogelaar (2004) pointed out the empirical evidence (e.g., Kopp & Smith 1983) on time trends being poor proxies for innovation and the introduction of new technologies. Following Baltagi & Griffin (1988), they considered a composite index of technology to reflect the discontinuity in technological progress. The index is a weighted sum of time dummies. Using data on hospital costs in the Netherlands for the period 1993-2000, they found that technological change, as proxied by the index, appeared to have substituted medical personnel and material supplies for nursing personnel.

The two main categories of medical technology are drugs and devices. In 2006, pharmaceutical products accounted on average for some 19% of total health expenditures in high-income countries (ranging from 8.7% up to 32.4%). According to the European Commission, in 2011, the share of medical devices in health expenditures represented less than 5% in EU member states, ranging from 3% in Germany to 5% in Sweden (European Commission 2012) whereas Donahoe & King (2011) estimate that spending on medical device as a share of National Health Expenditures in the U.S. increased slightly from 5.3% in 1989 to 5.9% in 2009.

In this paper we propose to introduce the total number of new drugs and medical devices as a direct indicator of medical technology in an econometric estimation of healthcare expenditures in OECD countries. In our view, these variables are more appropriate to proxy medical technology than the variables used in previous studies. R&D expenditures only reflect the input of the innovation process, which also depends on non-R&D expenditures, and many R&D expenditures do not result in any

[3] Single Photon Emission Computerized Tomography.

meaningful innovation.[4] Moreover, Pammolli et al. (2005) pointed out the inadequacy of the (NACE) industry classification that is used for official R&D statistics. Using a (linear) time trend to proxy the evolution of medical technology does not seem appropriate as data on the approval of new drugs and medical devices show no clear monotonous trend. Paul et al. (2010) report evidence on the decrease in productivity of the R&D activities of pharmaceutical companies. In spite of substantial R&D expenditures the number of innovative medicines approved by the FDA and other regulatory authorities in the world decreased.[5] In a recent report, the consulting firm PricewaterhouseCoopers (PwC) pointed out that the $1.1 trillion that pharmaceutical and biotech companies spent on R&D between 2002 and 2011 did not result in many new medicines. The average cost of a new molecule rose to $4.2 billion in the last five years of the period 2002-2011, 50% more than in the first half of the period. Some large pharmaceutical companies have reduced their R&D expenditures in response to the dismal performance (PricewaterhouseCoopers 2012). The weak performance of R&D portfolios appears to have resulted in consolidation in the pharmaceutical industry, with companies enhancing their pipeline through mergers and acquisitions. Whereas the number of blockbuster drugs launched in the last decade remained relatively stable, the average value fell. Companies started to focus only on those drug candidates believed to be scientifically robust and reduced the number of therapeutic areas (e.g., shifting towards cancer; diabetes and Alzheimer) in which they operate (Arrowsmith 2012). Pammolli et al. (2005) considered the introduction of new devices as a more reliable measure of inventive output in the medical devices industry than patents or scientific publications. Data on new devices approved by the FDA over the period 1990-2003 show that after a slight increase at the beginning of the period considered the number of pre-marketing notifications decreased whereas no clear trend appears for pre-market approvals. The evidence reported above shows that the link between R&D expenditures and the introduction of new drugs or medical devices is not straightforward and that innovation in medical technology does not follow a clear monotonous trend. Okunade (2004) argued that the assumption of technological change and innovation as a smooth process is not very realistic, urging to view technological progress as a lumpy process with nonlinear diffusion paths and random discoveries. A composite index (i.e., weighted sum of time dummies) to proxy technological change, as used by Blank & Vogelaar (2004), seems an improvement over the use of a time trend as it does not assume technological progress and medical innovation to follow a smooth path but, in our view, still suffers from attributing all omitted time-variant effects to medical technology. As the cost effectiveness of specific medical technologies differs substantially and there is moreover a strong correlation between individual technologies, the use of the total number of the two main categories (drugs and devices) seems more appropriate to assess the impact of medical technology on total health expenditures. Following Lichtenberg (2007), Cïvan & Köksal (2009) used the average age of drugs (the number of years passed since the drug was first approved by the FDA) as indicator of technological progress to assess its impact on health expenditures in US states. They argue that the use of their aggregate indicator permits to assess the potential 'treatment expansion effect' of new drugs. The latter effect was labeled by Cutler & McClellan (2001) who distinguished this effect from the 'treatment substitution effect', i.e. new technologies substituting for older technologies in the treatment of patients.

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4 Less than 1% of the drug candidates that are examined in pre-clinical tests get through to the stage of human testing and only 22% of the candidates that get through are developed and approved by the FDA (Grabowski 2002).

5 Munos (2009) argues that the spike in NME approvals in the first half of the 1990s was an exception to the general flat trend since the 1950s and that since 1996 NMEs appear to have reversed to the basically constant approval rate. A similar argument can be found in Kaitin & DiMasi (2011).

4. Data and descriptive statistics

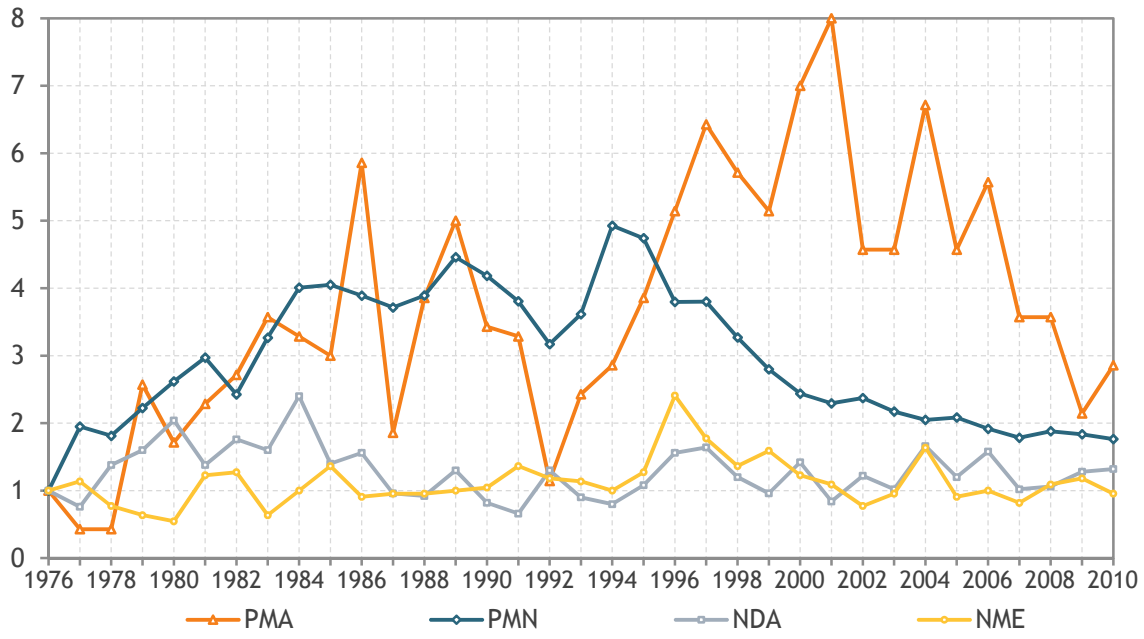
In this paper the number of new drugs and medical devices approved by the U.S. Food and Drugs Administration is used as a direct indicator of medical technology innovation in OECD countries. The Food, Drug and Cosmetic (FD&C) Act, signed by President Roosevelt in 1938, required manufacturers to provide evidence to the FDA on the safety of drugs before they could be marketed and also introduced consumer protection over medical devices. In 1962 Congress amended the rules for new drugs to require that companies, in addition to safety, also demonstrated the effectiveness of new drugs through clinical trials. The FDA distinguishes new drug applications from new molecular entities, the latter being new chemical structures that have never before been used in clinical practice. The Medical Device Amendments of 1976 to the FD&C Act established three classes for medical devices (I, II and III), based on the controls that are required to establish safety and effectiveness. Class III - defined as a device that supports or sustains human life or is of substantial importance in preventing impairment of human health or presents a potential, unreasonable risk of illness or injury – is subject to the strictest regulation. All Class III devices require pre-market approval (PMA) by the FDA to establish safety and effectiveness. For all other medical devices a 510(k) pre-market submission should be made to the FDA in which manufacturers have to demonstrate that their device is at least as safe and effective (i.e., substantially equivalent) to a legally marketed device. The FDA will reclassify a device as Class III, and therefore subject to PMA, if it is considered not to be substantially equivalent.[6]

Graph 1 shows the evolution of the number of original pre-market approvals (PMA) and 510(k) pre-market notifications (PMN) of new medical devices as well as the number of new drug applications (NDA, excluding NME) and new molecular entities (NME) over the period 1976-2010, , starting with the adoption of the Medical Device Amendments of 1976 to the FD&C Act. As the number of approvals differs substantially between the four categories, all series have been indexed to their initial level in 1976 (set at 1).[7] In line with previous evidence (e.g., Pammolli et al. 2005), the graph reveals that innovation in medical technology does not follow a monotonous (rising) trend.

[6] Information from the U.S. Food and Drug Administration website (http://www.fda.gov).

[7] Over the period 1976-2010, the average annual number for pre-market approvals was 26; for 510(k) pre-market notifications 3198; for new molecular entities 25 and for new drug applications 64.

Graph 1 New drugs and medical devices approved by U.S. FDA, 1976-2010 (1976 = 1)



Source: Own computations based on data from U.S. FDA on approvals (www.fda.gov)

Although, in our view, the number of approvals of new drugs and medical devices is more appropriate as an indicator of innovation in medical technology than previous proxy variables, there are obviously also limitations. The number of new products is a count variable that does not account for differences in purchase price or potential impact on health care costs (e.g., treatment expansion vs. treatment substitution as pointed out by Cutler and McClellan 2001, or the recent typology of cost effectiveness of medical technology by Chandra & Skinner 2012). The range of medical devices for which approval is needed is wide, and their potential impact on spending probably varies accordingly. However, in contrast to R&D expenditures or even patent count data, approval data reflect technology that is ready for introduction in the marketplace. Our use of U.S. data on new drugs and medical devices to reflect medical technology in OECD countries in this study is prompted by the lack of sufficiently long time series for other countries.8 Despite the obvious differences in regulation between the U.S. and other OECD countries, the leading role of the U.S. in both manufacturing of pharmaceuticals and medical devices and as a market is well-established (e.g., EFPIA 2012 and Pammolli et al. 2005). As such new medical technology marketed in the U.S. is likely to be a good proxy of innovation in medical technology worldwide. Munos (2009) pointed out that as the pharmaceutical industry is global and the US its largest market, eventually most new molecular entities are submitted for approval to the FDA.

[8] To the best of our knowledge, no long time series on approvals of new medicines and medical devices exist for other OECD countries. Data on new medicines approved by European Medicines Agency are only publicly available from 1996 onwards. The European Databank on Medical Devices (Eudamed), introduced in the Medical Device Directive of 1998 can only be accessed by the regulatory authorities and – given the rather recent EU regulation on medical devices – only contains data starting in 2003. A centralized authorization procedure for medicinal products was established in the EU through Regulation 2309/93. The European Medicines Agency (EMA) began to operate in 1995. Substantial amendments to the regulation were adopted by the European Parliament in 2004, containing provisions on the marketing, authorization, manufacturing and distribution of medicines.

Total health expenditures over the period 1981-2009 were obtained for 18 countries [9] from the OECD Health Data 2011. They were expressed in real per capita terms using US dollar PPP conversion rates.

Following the literature, in addition to the technology indicators three other potentially important structural determinants of health care expenditures have been used in the empirical model discussed in the next section: income (defined as real per capita GDP), the share of public relative to total health care spending, and the age composition of the population. GDP data were obtained from the OECD Annual National Accounts database and converted to real per capita values (again using the $PPP conversion factor). The share of public in total health spending was obtained from the OECD Health Data 2011. International comparative studies suggest that it may be a relevant variable, under the hypothesis that the propensity to consume health care services may differ according to the way the spending is financed (Gerdtham & Jonsson 2000). The age composition of the population was defined as the shares of the population aged 65-74, 75-84 and 85+ years old in the total population. These data were computed from the OECD Population database by 5-year age groups.

Table 1 summarizes the key features of the data used to estimate the model in the next section. It shows simple averages, minima and maxima of the model variables in 1980 and 2009, computed over the countries for which the data were available. The results illustrate the steep rise of health expenditures as a percentage of GDP, the rather stable share of public spending in total health spending (but with wide variation across countries), and the onset of demographic ageing (especially the doubling of the share of the oldest old).

Table 1 Descriptive statistics of model variables (1980/2009)

Key data Variable	Average 1980	Average 2009	Minimum 1980	Minimum 2009	Maximum 1980	Maximum 2009
HE % GDP	3.8%	13.8%	2.8%	10.5%	5.5%	21.6%
Pub %	75.7%	74.3%	41.0%	47.7%	95.0%	85.0%
Age 65-74	8.0%	8.7%	5.9%	6.2%	9.9%	12.0%
Age 75-84	4.0%	5.6%	2.7%	3.6%	5.2%	7.9%
Age 85+	0.9%	2.1%	0.5%	1.2%	1.2%	2.9%

[9] Austria, Belgium, Finland, France, Germany, Ireland, Italy, the Netherlands and Spain from the euro zone, and Australia, Canada, Denmark, Japan, Norway, Sweden, Switzerland the United Kingdom and The United States from the rest of the world (including non-euro zone European countries).

5. The model: specification and unit root test

As the empirical model described below is a log-linear panel model, we performed panel unit root tests on the logs of the country-specific variables. The results of these tests are presented in Table 2.

Table 2 Panel unit root tests for model variables 1981-2009

	Levels	First differences	
	Constant	Constant + Trend	No constant, no Trend
Real per capita health exp	3.921	-1.973 **	-7.904 ***
Real per capita GDP	0.061	3.779	-3.312 ***
Age 65-74	1.295	0.155	0.086
Age 75-84	-0.053	2.756	0.441
Age 85+	1.465	1.108	-2.508 ***

Notes: All variables in logarithms. Panel unit root tests are Im-Pesaran-Shin (IPS) tests with 2 lags.
***,**,* coefficients smaller than zero at <0.01, < 0.05, and < 0.10 tolerance levels respectively.

Real per capita health expenditures are non-stationary or trend-stationary. Real per capita income also contains a unit root in levels. Both variables are stationary after differencing. The age composition variables do not exhibit a clear order of integration, except for the age group 85+ which appears to be I(1). The technology variables are common to all countries, so their stationarity was tested using the Augmented Dickey-Fuller test. The results, presented in Table 3, indicate a unit root in the levels of the variables. Taken together, the unit root test results do not preclude the existence of a cointegrating relationship between (log) health expenditures and its potential determinants.

Table 3 Unit root tests for technology variables 1981-2009

	Levels	First differences		
Technology	Constant	Constant + Trend	No constant, no trend	Technology
NDA	-2.275	-2.139	-5.445 ***	NDA
NME	-3.041 **	-2.593	-5.577 ***	NME
PMN	-0.567	-2.153	-3.181 ***	PMN
PMA	-2.260	-1.743	-3.674 ***	PMA
NDA stock	-2.589 *	-2.569	-3.809 ***	NDA stock
NME stock	-2.578 *	-0.222	-1.743 *	NME stock
PMN stock	-1.734	-2.430	-2.158 **	PMN stock
PMA stock	-2.536	-1.943	-2.747 ***	PMA stock

Th Notes: All tests Augmented Dickey-Fuller tests with 2 lags.
***,**,* coefficients smaller than zero at <0.01, < 0.05, and < 0.10 tolerance levels respectively.

The literature on aggregate health care expenditure models provides very little guidance on the precise form of the hypothesized relationship between the outcome variable and its determinants, both in terms of its functional form and its dynamics. We therefore postulate the following general model:

$$y_{it} = \alpha_0 + \sum_{j=1}^{2} \alpha_j x_{it-j} + \delta p_{it} + \sum_{k=1}^{3} \beta_k a_{k,it} + \sum_{l=1}^{4} \sum_{j=1}^{5} \gamma_{l,j} t_{l,t-j} + \varepsilon_{it}$$

The disturbance term has the familiar one-way error-component structure:

$$\varepsilon_{it} = \mu_i + \nu_{it}$$

y is total health care expenditures per capita in constant prices; x is GDP per capita in constant prices; p is the share of public in total spending; a_k is the share of age group k in the total population (k = 1: 65-74 year; k = 2: 75-84 year; k = 3: 85+ year) and t_l is the number of approved new medical technologies (l = 1: drugs [NDA]; l = 2: molecules [NME]; l = 3: device approvals [PMA]; l =4: device notifications [PMN]). All variables are in logarithms. The lags of the independent variables were determined as follows: the public share and age composition variables are contemporaneous with the dependent variable, since their impact is immediate by definition. The income variable was included with one and two lags, in order to avoid endogeneity [10]. The technology variables have longer lags, in order to accommodate the potentially long lags involved between the approval of the product and the ultimate diffusion of new medical applications. In light of the discussion in section 3, we have included all lags between 1 and 5 years after the technology was approved.

The technology variables as defined here can be interpreted as representing technologies with a maximum lifespan of five years, after which period they become obsolete. An alternative approach consists of constructing capital stock series from the observed flow variables (see also Lichtenberg 2005). An obvious difficulty is to determine the relevant depreciation rates and initial capital stocks, but this can be overcome by experimenting with different depreciation rates. In the empirical work discussed in the next section, we have used capital stock variables based on 5, 10 and 15 percent depreciation rates for each of the technology proxies, using the perpetual inventory method. The unit root tests for the capital stock series based on a 10 percent depreciation rate are reported in Table 3.

The choice of the panel model specification was based on two consecutive tests: the Breusch-Pagan Lagrange Multiplier test to test Plain OLS (OLS) against the Random Effects (RE) alternative, and the Hausman test to test RE against Fixed Effects (FE). On the basis of these tests, the model was estimated using the fixed effects estimator.

10 Since income is introduced as a predetermined variable, it can be treated, at least asymptotically, as an exogenous variable (Greene 2008).

6. Results and discussion

The model was estimated with explicit lags of the technology variables and with the technology capital stocks, obtained with different depreciation rates. The results are presented in Table 4. For the model with explicit lags the total elasticities (the sum of the estimated coefficients over the lags) are reported in column 2. For the capital stock model the results refer to the combination of depreciation rates that seemed most appropriate for the respective technology categories (column 4) [11]. The results with exclusion restrictions on the set of technology variables are shown in column 3, together with the likelihood ratio test of the restrictions.

Table 4 Estimated total long-run elasticities of income, age composition and medical technology on total health expenditures

Model Variables	Explicit lags	No tech variables	Capital stock
GDP	1.201 ***	1.791 ***	0.989 ***
%Pub	0.257 **	0.356 **	0.311 ***
Age 65-74	-0.225 ***	-0.416 ***	-0.127 **
Age 75-84	-0.038	0.109	-0.119 **
Age 85+	0.287 ***	0.612 ***	0.160 ***
NDA [a]	-0.582 ***		-0.550 ***
NME [c]	0.668 ***		0.433 ***
PMN [b]	-0.675 ***		-0.405 ***
PMA [b]	0.316 ***		0.523 ***
Model specification tests			
LR test		322.9 ***	
Residual stationarity [d]	-1.92 **	0.148	-2.15 **

Notes: ***,**,* estimates different from zero at <1%, < 5%, and < 10% tolerance levels respectively, two-sided tests.
a,b,c Capital stock computed with 15%, 10% or 5% depreciation rate respectively.
d Im-Pesaran-Shin tests with 2 or 3 lags.

As expected, income is an important determinant of health care spending. Its estimated elasticity is between 1 and 1.2, except in the model where the technology variables were omitted. The estimated income elasticity increases to 1.8 and the residual stationarity test fails when excluding the technology proxies. The high value for the income elasticity obtained with a model lacking technology proxies confirms similar results reported in the literature, where the income elasticity drops substantially when a time trend or other technology proxy is introduced. In addition to their statistical significance, the approval variables used in this study have the advantage of actually measuring a feature that is directly relevant to medical technological progress, while a linear trend may capture the effect of any number of non-stationary determinants on health expenditure.

The share of public spending in total spending also has the anticipated positive effect on total spending, implying that a public funding system seems to be more generous than a private system. However, this does not necessarily imply that the latter is more efficient, since a public system may provide

[11] The choice of depreciation rates was based on the statistical results obtained from preliminary estimation (goodness of fit and specification tests). The results with different combinations of depreciation rates were similar to the ones reported here.

broader coverage.

The effects of the age composition of the population paint a rather subtle picture of the effects of ageing on health spending: the share of the younger elderly has a significantly negative impact while the share of the oldest old in the population significantly increases spending. The effects are similar in magnitude, and this possibly explains why many empirical studies in which only a single age composition variable is included, do not find significant effects.

Turning to the estimated effects of drug and medical device approvals on spending, the effects of all four variables are highly significant. Remarkably, two approval classes have positive and two have negative effects: the number of approved new drugs (NDA) and devices (PMN) have a negative effect, while the number of approved pharmaceutical products based on new molecules (NME) and new 'Class III' devices (PMA) have a positive effect. These results suggest that 'radically' innovating products are expensive and therefore cost-increasing, while the net effect of 'incrementally' innovating products appears to be cost-saving. A plausible explanation is that radical innovation leads to 'treatment expansion', while incremental innovation leads to 'treatment substitution' (see Cutler & McClellan 2001). The cost-increasing effect of radical medical progress confirms the consensus view about technology as a 'major driver' of health expenditures, but the cost-saving effect of incremental progress may appear counterintuitive. Our explanation is based on the substitution effect discussed in section 2: the net effect of some new drugs and devices, even when they are expensive when introduced, may very well be negative because they lower the use of other (costly) medical interventions.

The net cost-saving effect of some drugs and devices on health expenditures has important implications for policymakers responsible for designing and implementing cost containment programs: if the costs of reimbursing new products are evaluated separately from other medical expenses, there is a danger that the reimbursement decisions will be overly restrictive, thereby limiting the use of technology that might ultimately save costs. Our results suggest that cost containment policies should carefully take into account the potential of new drugs and devices to substitute for other medical interventions.

The model estimates can also be used to shed some light on the Newhouse conjecture discussed earlier. Multiplying the coefficients of model 3 with the observed growth rates of the corresponding variables reveals that the combined technology variables contribute 69% on average (ranging between 50 and 75%) of the explained historical growth at the country level (see Table 5). Income growth accounts for 26% on average (ranging between 18 and 49%), while the age composition of the population contributes a modest 5% on average (ranging between 2 and 9%). The share of public in total spending has no discernible effect on average. These results do not seem to contradict Newhouse's claim. If anything, they suggest that medical technology accounts for an even greater share of the historical growth than is widely assumed. It should be noted, however, that our estimates do not take medical price inflation into account. Using Smith et al.'s (Smith et al. 2009) estimate that medical price inflation accounted for up to 19 percent of the historical increase in health spending, and assuming that this effect is captured by the technology proxies in our model, our results are qualitatively comparable to theirs [12].

[12] Smith et al. 2009 cover a longer time period (1960-2007) and 22 OECD countries in their analysis.

Table 5 Estimated total contributions of income, share of public spending, age composition and medical technology on historical growth of total health expenditures 1980-2009

Variable Country	Income	Share of public spending	Age composition	Technology
AT	26%	2%	5%	68%
BE	24%	0%	4%	72%
FI	28%	-1%	6%	66%
DE	24%	0%	5%	72%
NL	24%	-1%	2%	76%
ES	30%	-1%	4%	66%
FR	20%	0%	5%	75%
IRL	49%	-1%	3%	49%
IT	20%	0%	9%	71%
AU	27%	1%	3%	68%
CA	22%	-1%	3%	76%
CH	18%	4%	7%	71%
DK	24%	0%	4%	73%
JA	29%	1%	5%	65%
NO	31%	0%	5%	64%
SE	25%	-2%	6%	71%
UK	30%	-1%	3%	68%
US	26%	2%	3%	69%
Average	26%	0%	5%	69%
Minimum	18%	-2%	2%	49%
Maximum	49%	4%	9%	76%

Note: Computations based on shorter period for NL, IT, AU, CH and JA due to incomplete data

The overall technology effect that follows from our model conceals very heterogeneous effects: the net positive contribution of medical innovation to the historical growth of health spending is largely due to the introduction of new Class III devices (PMA, +65%) and molecules (NME, +14%), while incremental innovation, both in drugs (NDA, -2%) and devices (PMN, -9%), have a negative net effect on aggregate spending.

7. Conclusion

This paper reassesses the widely held view that the introduction of new medical technology has been responsible for a substantial part of the growth of health expenditures in advanced economies over the past three decades. Ever since Weisbrod's seminal paper, health economists have tried to measure the contribution of technology on health spending empirically. This paper contributes to this literature by introducing data on the number of approved new medical products as a proxy for medical technological innovation, and we believe this is a major advance over the proxies conventionally used, such as linear trends, specific technology indicators or R&D expenditures. The new products data were summarized in four variables, reflecting medical innovation in new molecules (NME), other drugs (NDA) and two classes of new devices (PMA and PMN) respectively. These four variables define two broad classes of technology (pharmaceutical products and devices), each of which is subdivided in two subgroups to differentiate between 'radical' (NME for drugs and PMA for devices) and 'incremental' (NDA for drugs and PMN for devices) medical innovation. The variables were alternatively introduced in the model with explicit lags and as technology capital stocks.

The results obtained with a panel model for 18 OECD countries over the period 1981-2009 can be summarized as follows. First, statistical tests on the exclusion of the technology variables were strongly rejected, confirming their necessity in a correctly specified model of total health expenditures. Second, the net overall effect of medical technology on spending is positive, mainly caused by new Class III devices (PMA) and, to a lesser extent, new molecules (NME). Incremental medical innovation, both in drugs and devices, has a negative effect on spending. This finding corroborates results reported in the literature about the cost-reducing effects of new drugs that avert or reduce the use of other medical interventions. Third, estimated income elasticities of health spending vary between 1 (using the technology stock variables) and 1.2 (using explicit lags of the technology variables). Fourth, the age composition of the population overall has a positive but modest effect on spending, while the share of public in total spending is significant but small.

According to our calculations, medical technological change accounted for as much as 69% of the explained growth of total real per capita health expenditures over the 1981-2009 period. Since we did not attempt to correct for medical price inflation, this estimate is probably biased upward. Nevertheless, it does not seem unreasonable to conclude that technology is indeed a major driver of health care spending, possibly accounting for as much as half the observed historical growth in expenditures. As regards the age composition of the population, it should be noted that the small historical contribution to spending does not imply that ageing will not be important in the future. Our estimates indicate a positive effect of the share of age group 85+ in the population, a share that is expected to increase substantially in many OECD countries over the coming decades.

The main contribution of this paper is the introduction of new proxies for medical technological innovation, which have allowed us to estimate the effects of technology, income, demographics and health care financing directly. We think this approach constitutes a significant improvement upon alternative econometric models based on other proxies such as time trends, specific technology indicators or technology inputs such as R&D spending. It also avoids the imputation of effects typically used in re-

sidual-based models (the growth accounting framework). The results confirm the importance of technology as a driver of spending, but they also indicate that not all innovation is necessarily cost-increasing. Moreover, many of the technologies that do push up spending probably improve medical outcomes substantially, implying an increase in real output that is not captured by the observed expenditure data. The differential effects for types of approvals obtained in this study also suggest that it may be worthwhile to disaggregate the approval data even further, in order to obtain an even more detailed picture of the effects of various technologies on medical expenditures. Another promising direction for future research would be to use national approval data instead of FDA data.

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