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The impact of technological advancements on health spending: A literature review

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THE IMPACT OF TECHNOLOGICAL ADVANCEMENTS ON HEALTH SPENDING - A LITERATURE REVIEW

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Abstract

The measurement of the impact of technology as a driver of health care expenditure is complex since technological effects are closely interlinked with other determinants such as income and the composition and health status of a population. Furthermore, the impact of the supply of advances in technology on health expenditure cannot be considered in isolation from demand and the policy context and the broader institutional context governing the adoption of new technologies. Hence, it is the interaction of supply and demand factors and the context that determine the ultimate level of technology use.

There are also important quality changes that come with technological progress that also have monetary costs and benefits attached. Modelling quality improvements, both in terms of benefits within the health system and outside (e.g. its impact on life expectancy, ageing populations, productivity and GDP), is a challenging task, and no macroeconomic models to date have tried to capture them.

This paper presents a comprehensive literature review of the impact of technological advances on health expenditure growth, the 'cost' side of the equation.

Across the studies considered in this paper, the estimated impact of technological progress on health expenditure growth ranges significantly – from 10 to 75% of the observed annual growth of health expenditure, with most of the studies reporting values between 25 and 50%.

Applying an average value from the literature – that is 35% - to growth rates of health expenditure observed across OECD countries, we estimate that technological change accounted for around 1% of annual growth in health spending from 1995-2015. Under the assumption that technological progress keeps its contribution to health spending growth constant and taking into account available projections, this would imply that technological change would increase health spending by 0.9% annually up to 2030.

Résumé

La mesure de l'impact de la technologie en tant que facteur déterminant des dépenses de santé est complexe puisque les effets technologiques sont étroitement liés à d'autres déterminants tels que le revenu, la composition et l'état de santé d'une population. En outre, l'impact de l'offre de progrès technologiques sur les dépenses de santé ne peut être considéré séparément de la demande, du contexte politique et du contexte institutionnel dans son ensemble, autant de facteurs qui influencent l'adoption de nouvelles technologies. C'est donc l'interaction des facteurs d'offre et de demande et le contexte qui déterminent le niveau ultime de dépenses et d'utilisation de la technologie.

Les progrès technologiques apportent ainsi d'importantes améliorations en termes de qualité des soins de santé, auxquels s'ajoutent des coûts monétaires ainsi que des bénéfices. La modélisation des améliorations de la qualité, à la fois en termes de bénéfices directs et indirects sur le système de santé (c'est-à-dire son impact sur l'espérance de vie, le vieillissement de la population, la productivité et le PIB, etc.) est une tâche ardue et aucun modèle macroéconomique n'a jusqu'à présent tenté de les prendre en compte.

Cet article présente une revue littéraire exhaustive de l'impact des progrès technologiques sur la croissance des dépenses de santé, le côté « coût » de l'équation.

Selon les études examinées dans le document, l'impact estimé des progrès technologiques sur la croissance des dépenses de santé varie considérablement, allant de 10 à 75% de la croissance annuelle observée des dépenses de santé. La plupart des études indiquent des valeurs comprises entre 25 et 50%.

En appliquant une valeur moyenne tirée de la littérature - soit 35% - aux taux de croissance des dépenses de santé observés dans les pays de l'OCDE, nous estimons que le changement technologique représente environ 1% de la croissance annuelle des dépenses de santé de 1995 à 2015. Dans l'hypothèse que l'impact des progrès technologiques sur la croissance des dépenses de santé reste constant et si l'on se base sur les projections disponibles, les changements technologiques contribueraient aux dépenses de santé à hauteur de 0.9% par an jusqu'en 2030.

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1. Introduction

1. Health care expenditure (henceforth HCE) has outpaced economic growth across OECD countries over recent decades – more than doubling as a share of GDP since 1970. Gaining an understanding of the underlying drivers of HCE growth has been central to the analysis in recent literature – in order to devise relevant policy strategies to tackle growth, it is crucial to understand the mechanisms that drive such growth.

2. Technological progress is widely understood to be a major driver of health expenditure growth, and is the main focus of this study. However, to better understand the impact of technology, it is first important to understand other key determinants of health expenditure growth, since technological effects are closely interlinked with these other determinants. A recent OECD study (Marino et al., 2017) focussed on reviewing the macroeconomic drivers of HCE growth across OECD countries and identified three other major contributors alongside technology: demographic factors; income; and productivity.

3. Demographic factors, or 'ageing', includes effects related to the composition and health status of a country's population. Both increases in population size and changes to the age structure of the population (in particular, population ageing) exert upward pressure on expenditures. Reductions in mortality and morbidity, and corresponding increases in life expectancy, are generally thought to exert downward pressure on expenditures, as 'healthy ageing' theories have shown that longer life expectancy may result in healthier cohorts which are in turn less expensive to the health system. These theories have been tested through the analysis of 'time to death', a theory suggesting that the bulk of individual expenditure is concentrated in the last year(s) of life.

4. Demand for higher quality and more accessible services has driven much of the observed increases in health expenditure over the last twenty to thirty years. In particular, rising incomes have elevated expectations of what health systems should deliver. Therefore, income growth is one of the main determinants of HCE growth, with income elasticity measuring how much GDP growth is converted into HCE growth in any given year. Intuitively, this measures individuals' and countries' willingness to pay for better health. Most studies have found that as countries get richer income elasticity tends to fall, with high-income countries averaging around 0.75, making health a necessity good. This finding suggests that once an adequate level of care is reached, elasticity decreases. However, income gains remain the main contributor to HCE growth.

5. Inflationary effects on health expenditure stem from the low productivity of the health sector as compared to the general economy (Baumol "cost disease"). Baumol's theory (Baumol 1967) suggests that such low productivity, labour-intensive sectors of the economy (which he calls 'non-progressive') are bound to experience constant, above-average wage inflation in order to remain on track with 'progressive' sectors of the economy, where wages are driven upwards by increases in productivity growth as the labour share falls.

6. Importantly, some drivers of HCE growth are accompanied by relative increases in health care quality (such as those driven by most new technologies), while others are inflationary effects that come from either changes in the size and structure of the population and health status or monetary factors that affect prices without necessarily increasing quality (i.e. wage growth, or the Baumol effect). Furthermore, their contribution to health expenditure growth is different in magnitude, with some drivers (i.e. income) contributing half or more of the growth.

7. Technological progress has often been referred to as one of the main drivers of health expenditure growth, as it has expanded the scope of treatments and diagnostics, especially in high-income countries (Smith, Newhouse and Freeland, 2009). Technology is also a causal driver of many of the other variables used to explain HCE growth: we can reasonably infer that increases in life expectancy and reductions in mortality are partly explained by new technologies that improve health outcomes; that GDP growth itself is related to technology as the main driver of productivity

increases[1]; and, for the same reason, that the price effect stemming from the Baumol's cost disease is also highly related to technological change, since the effect is mainly driven by the labour-displacing nature of technological change in progressive sectors of the economy.

8. At the same time, it should be recognised that technology does not have a simple, one-directional effect. That is, certain technologies can be cost saving: telemedicine, for example, can potentially reduce the cost of care. Nevertheless, the aggregate effect of technology on health expenditure is still understood to be cost increasing. Different estimates of the impact of technological progress on health expenditure exist. For example, Chernew and Newhouse (2012) find that estimates in the literature range between 20% and 70% of total HCE growth, while Willemé and Dumont (2015) report that technological advances accounted for around one-third of the growth in total HCE in a panel of 18 OECD countries covering the period 1981 and 2012. Smith and her collaborators (2009), using panel data across 23 OECD countries from 1960 to 2006, estimate that technology explains 27-48% of health expenditure growth.

9. This paper is structured as follows. Section 2 defines the concept of technology as a driver of health care expenditure, assessing the different mechanisms of action and pressures it exerts on spending growth, as well as the quality-increasing nature of the driver. Section 3 then details the most common approaches used in the literature to model technology as a driver of spending growth (as a key component of models of health expenditure). Section 4 presents a review of the main studies and estimates of the impact of technology on health expenditure. Finally, section 5 discusses the key findings of this literature review.

[1] Economic growth models identify technological progress is one of the key determinants of productivity growth in the overall economy (often measured as GDP per employee). It follows logically that a proxy of general technological progress will be in some way endogenous to GDP growth within a regression model. We will see later in the paper that some of the literature tries to decouple this effect by calculating a joint income-technology elasticity coefficient to single out the share of income elasticity that captures technological effects.

2. Conceptualising technology as a driver of health care expenditure

10. Defining technology as a driver of health expenditure is not straightforward. Broadly speaking, the term 'technology' refers to the procedures, equipment and processes by which health care is delivered. In economic terms, technology is usually defined in terms of inputs, or factors of production, the most common being labour, knowledge and capital (Moise, 2003). Technological change[2] is defined as any change in products, procedures and practice styles that alter the way care is delivered (OECD, 2017; Congressional Budget Office, 2008). These advances include new drugs, devices or services, new applications of existing procedures, newly developed technologies (Chernew and Newhouse, 2012; Abrantes-Metz, 2012) as well as innovations in processes and care delivery brought about by – as an example - big data (European Commission 2014), biosensitive wearable technologies, smartphone adoption and 3D printing (Imison et al., 2016; OECD, 2017). Technological progress can extend the scope and range of health care goods and services provided, innovate care pathways and workflow and enhance quality of health care.

11. Importantly, this definition of technology does not inherently assume a cost-increasing nature for the driver in itself. Different types of technology affect HCE growth with different mechanisms of action, some of which may be cost decreasing and others cost increasing.

2.1. Mechanisms of action through which technology affects health care spending

12. The interactions between technology and spending are complex. While in other sectors of the economy, technological progress often allows for a cost reduction by increasing the efficiency of the production process and using less labour input as well as by featuring more technological innovations, this is usually not the case in health care where there is also technological innovation in processes, but the reduction in labour is less impacted while the new treatments/devices are multiple.

13. Despite the fact that several innovations have proved cost decreasing per treatment (micro level), technological progress has accounted for the bulk of health expenditure increase over time on an overall level by altering treatment pathways (macro level) (Chernew and May, 2011). To bridge micro and macro levels, Retting (1994) and Pammolli et al. (2005) identify the following "mechanisms of action" through which technological progress affects health care spending:

- new product (e.g. a new pharmaceutical) or equipment that allows a new service to be provided (e.g. mobile health applications);
- full or partial substitution for current approaches (e.g. laparoscopic techniques to substitute for the traditional open procedures);
- increased use of pre-existing services also by expanding the indications for a treatment (e.g. prostate cancer screening leading to more prostatectomies);
- development of treatments for conditions once regarded beyond medicine boundaries, such as mental illness and substance abuse; and
- life-extending effect of new technologies, for which each survivor will generally consume additional health care goods and services over their now longer life.

14. Thus, an important determinant of the impact of a new technology on expenditure is the degree to which it substitutes for, or complements, existing technologies in the treatment or diagnosis of a disease. Most technological progress generates changes in both complementary and substitute services. What matters for overall health expenditure trends is how use patterns change on balance, which in turn depends on the responsiveness of the demand for all services with respect to the innovation and the relative costs of the services (Chernew and Newhouse, 2012).

[2] The paper uses technological advances or technological progress interchangeably.

15. These mechanisms of action offer a distinct perspective compared to a categorisation of technology that relies on the *type* of technology itself. Chernew and Newhouse identify three main types of technology:

- Product innovation, which is defined as new products or equipment that allows a new service to be provided;
- Knowledge innovation, defined as new discoveries that result in a new application of an existing product;
- Process innovation, defined as new knowledge that leads to a lower production cost of existing products or treatments.

16. Interestingly, these types of technology are not strictly defined by any particular mechanism of action (although they might operate primarily through one), and therefore their effect on HCE cannot be theoretically defined in advance. For example, knowledge innovation can result in either full or partial substitution of current approaches or increased use of pre-existing services – the first of which can be either cost reducing or cost increasing, depending on the relative cost-effectiveness of the new treatment approach, while the second is most likely cost increasing due to increased volumes (assuming that economies of scale do not apply in the traditional sense).

17. Therefore, different types of technology and the mechanisms of action through which they operate are complementary concepts. The first is useful in understanding how technology can be modelled, since it provides a reference point for identifying a suitable method or proxy for volumes and scope of technological progress. The second is useful in assessing the nature of the impact technology will have on expenditure growth, providing valuable theoretical insights on the sign and magnitude of the effect of the above mentioned changes in volumes.

2.2. Value and sustainability

18. It is important to point out that the focus of the analysis here is on the impact of technological change on health expenditure. However, the beneficial side effects of technological progress – longer life, improved quality of life, prolonged working ability, and so on – are also important. Understanding the impact of technology at the macroeconomic level makes drawing conclusion on the issue of the value that patients and society derive from such advances a challenging task. Macroeconomic studies have traditionally focused strictly on the cost side of the equation, with little effort devoted in trying to quantify whether the quality improvements brought by technological change are desirable and/or sustainable in the long run.

19. An indication of this effect is found in studies that explore the simultaneous relation of causality between health expenditure and GDP. These studies argue that better health, just like better education, significantly improves the quality and size of the human capital stock in society, which in turn fosters growth in the overall economy. Capturing the effect of this relationship is beyond the scope of this review, but it is important to acknowledge that higher costs resulting from technological progress might not capture the full picture, and that in the long run improvements in health status resulting from such costs might be repaid fully through additional gains beyond the health sector (Licchetta and Stelmach 2016).

20. As Cutler and McClellan (2001) point out, "it does not necessarily follow that technological change is therefore bad. Costs of technology need to be compared with benefits before welfare statements can be made. Technological change is bad only if the cost increases are greater than the benefits". The relationship between costs and quality of technological changes is ambiguous: some technologies might come with similar costs and higher quality (e.g. a new drug is introduced in the market, with better health outcomes and at a similar price than what is currently available).

21. However, a large number of technologies come with higher quality (or outcomes), but also higher costs – and in some cases higher costs for similar outcomes. Some technologies might reduce waiting times because they allow for increased volumes (e.g. a new diagnostic test that is much faster but just as precise as the next best alternative), while some others might increase them (e.g. a new

diagnostic test with much better precision, but slower and/or more expensive than the next best alternative) (Marino et al., 2017).

Box 2.1. Health Technology Assessment (HTA)

HTA aims at systematically and transparently evaluating the potential impact of introducing technologies into health care systems, and whether they achieve value for money. HTA concentrates its evaluation in three main domains: clinical evidence (such as the efficacy, safety and appropriateness of a particular intervention); economic evaluations; and in some countries, ethical and societal considerations. This provides an evidence-based means of informing policy makers' decisions about the allocation of public resources. With rapid technological advancements bringing more costly technologies, HTA's use is becoming increasingly important.

One of the main components of HTA is economic analysis. Some countries conduct cost-benefit analysis to estimate the incremental cost per quality-adjusted life year (QALY) gained, which can be interpreted as the additional cost per unit of health benefit gained in choosing one intervention over another. This tool can be used to determine at the health system level: cost-effective diagnostic and treatment pathways tailored to specific populations or sub-groups; the amounts of QALY displaced in the health system when a new drug is introduced at a certain price; whether a new treatment or drug should substitute or complement existing ones; and so on.

This approach is an imperfect science and is widely debated, but remains a useful tool in determining the cost-effectiveness of new interventions. A precise incremental cost-effectiveness ratio (ICER) threshold at which an intervention is considered cost-effective is difficult to determine, but the WHO suggests that health interventions with an ICER up to three times GDP per capita would be considered cost-effective (Bertram, 2015). Some studies have explored ways to precisely estimate a national cost-effectiveness threshold (Claxton et al., 2015) by undertaking a rigorous exercise of calculating how much a QALY is worth in monetary terms in the health system as a whole. This benchmark provides a useful normative tool in determining cost-effectiveness of a new technology, but it ultimately relies on a specific ethical assumption about what the objective of a health system should be (OECD, 2017).

22. The critical policy questions are thus whether the benefits of such expenditure outweigh the costs and how decisions can be made about what to prioritise in a resource-constrained system where new developments may add value but cost more (Castle-Clarke 2018). Research on comparative effectiveness could provide a basis for applying new technologies only when they add benefits that are greater than those conferred by less expensive technologies (Congressional Budget Office, 2008). Carrying out routine Health Technology Assessment (HTA) can ensure that publicly funded interventions represent high value for both payers and patients (see Box 2.1).

23. Chandra and Skinner (2012) group technologies into three categories based on their cost-effectiveness: I) highly effective care; II) treatments where there are clear positive gains for a subset of people receiving treatment, but with considerable heterogeneity in the marginal effectiveness across the population; III) technology with poor cost-effectiveness for the overwhelming majority of patients or where we simply do not know the value because of a lack of clinical studies.

24. The first type is technology that is effective in achieving its therapeutic aim and delivers high value. Cheap, "low-tech" technologies that can be broadly applied across populations feature strongly in this group. Costly interventions can also deliver considerable value if they are effective and their target population is clearly defined. Well-defined indication is a common characteristic of the costlier technologies of this type. Examples include the aseptic technique, vaccines, beta-blockers combined with aspirin, and antiretroviral treatment for HIV.

25. The second type includes technologies that, while effective in some indications, are prone to expanding their application across a population and to cases where their clinical utility is diminished. The decreasing marginal benefit dilutes the value derived from these technologies. Many diagnostic technologies (e.g. radiology and endoscopy) feature in this category. Cardiac catheterisation and angioplasty are other examples of a medical technology proven to benefit a certain

category of patient, but whose application crept into patient types that could be better managed in other, often more conservative and less costly ways.

26. Considerable geographic variation in the use of this second type of technologies is often observed, partly driven by factors other than population health need. This is one of the reasons why even technologies that are cost saving at individual level end up having an expansionary effect on aggregate expenditure: they are eventually applied to cases where they produce little benefit, thus undermining value.

27. The final type comprises technologies for which evidence of therapeutic benefit is weak or non-existent, and that are clinically equivalent to "watchful waiting" or less complex, conservative interventions. Many such interventions are costly in financial terms as well in the clinical risk posed by iatrogenic harm. They include some spinal surgery, a range of diagnostics such as liver function testing, and devices such as those that measure pulmonary artery pressure. Remarkably, provision (and reimbursement) of these interventions continues, despite decades of evidence for their lack of effectiveness in some cases.

28. Of note that new technologies may require important changes to the workforce – such as professionals learning to work in new ways (Vogel 2018) or entirely new roles – and to the workflows (Castle-Clarke 2018). This concept is also pivotal in understanding the inflationary effect of Baumol's cost disease, whereas technological progress in the health care sector does not displace labour at the same rate as in the general economy (if at all). While most of the inflationary wage effect comes from health professionals' wages 'picking up' productivity gains from the rest of the economy, some of these gains might also come from increased need for specialisation and training in the use of these new technologies, both in the workplace and in the form of longer, more complex educational pathways for students.

2.3. Challenges in measuring the contribution of technological progress to health expenditure growth

29. Rising individual and national income have been shown to be strong contributors to expenditure growth through demand for, and supply of, greater health coverage (Smith et al., 2009). The expansion and deepening of health coverage has nourished innovation in medical technology; and vice versa new technologies and new medical capabilities have expanded demand. Payers, both public and private, often agree to the demand through political or market mechanisms (Sorenson et al., 2013).

30. Farag et al. (2012) explains the interplay of insurance (loosely defined to include public coverage) and technology as such: "Technological change is known to influence cost increases particularly where health insurance is available since it facilitates the adoption of new technologies. The classic economic view is that insurance affects health care costs because it drives the marginal price of medical care close to zero, so that consumers demand care until the marginal product of additional care is nearly zero."

31. The effect of health technology can therefore not be seen as purely exogenous, that is, taken as given from the point of view of the analysis. A complex, dynamic interplay arises between several drivers: rising income (Slade and Anderson 2001), insurance coverage, financing mechanisms, disease patterns, regulation, and clinical practice style and medical culture. Thus, technological progress must be placed in the context of the institutional and regulatory environment within which it is shaped by organisations, the industry and individuals as well as by the remuneration and pricing for the use or application of technologies (Okunade, 2004; Australian Government Productivity Commission, 2005). This institutional and regulatory environment may also slow down the adoption of new technologies (Pearl 2014).

32. Hence, isolating the effect of technological progress on health care spending levels and trends can prove very difficult. In fact, technological change in the health sector represents the most complex and endogenous driver of health expenditure to model (Martin et al., 2011). Several considerations have already been made regarding its endogeneity, especially taken together with the ageing component, where variables such as life expectancy interact with both the demographic and

technological coefficients in ways that are not yet fully understood. Recent studies find that the impact of technology on individual expenditure increases non-linearly with age, and is therefore highly endogenous (Wong et al., 2012). Technological change has also been identified as the variable that is continuously and most rapidly changing in health care expenditure projection models (Chernew and Newhouse, 2012).

33. While the evidence suggests that, on balance, technology has a positive effect on expenditure, it should be kept in mind that this effect is composed of a positive and negative vector, depending on the definition of technology that is being used for the analysis. Moreover, depending on the method used to measure technological change (exogenous or endogenous variable), the estimate of its effect might incorporate policy effects or other confounding variables that are not specified in the model.

3. Approaches to measuring the contribution of technological change to health expenditure growth

3.1. Approaches to measurement

34. In this section, we look at how "technology" has been measured in recent literature. Several methods have been developed over the years, at different levels of aggregation of expenditure (individual, national, international) and consequently with different proxy techniques for the technology component (individual technologies, residual estimation and proxy estimation). We categorise the studies reviewed according to the latter: case study (or bottom-up) approach, residual approach and proxy approach.

35. It is important to note that the dependent variable of the study varies, especially depending on the level of aggregation of the sample. There is ample evidence that the level of aggregation has an important effect in the estimated value of model parameters – this is certainly the case for income elasticity, for which as the level of aggregation increases, income elasticity decreases drastically.

36. This makes sense from a theoretical perspective, since we would expect individuals' utility functions to behave differently than those of a government, or a panel of countries. Hence health care might indeed be a luxury good for an individual (as individual income goes up, the share of that income allocated to health care increases) but a necessity good for a panel of countries.

37. A similar mechanism might be at play with technological change: a potential example is the use of RX diagnostic tests even if not strictly necessary, or indeed advised. An individual's utility function could very well result in that individual purchasing the RX test because the individual benefit against the out-of-pocket cost of the item is high. However, a government will be much more reluctant to offer reimbursement on diagnostic tests that are not effective in a particular clinical pathway, and therefore will probably decide to only purchase the test when strictly necessary.

38. This is to say that the level of aggregation of the sample, and therefore the dependent variable (individual or national or international expenditure), matters. For the purpose of this study, we will focus mainly on total health expenditure, since this is the main frame of reference for most studies looking at driver impact on HCE. Nevertheless, we are aware that some studies use a different dependent variable to measure the impact of technology.

3.1.1. Microeconomic approaches: case studies

39. The case study approach looks at how specific technological advances – and the associated changes in clinical practice – affect spending. These studies generally use microeconomic data (at the individual or provider level) to measure the impact of the introduction of individual technologies on spending. As an example, the adoption of electronic medical records by ambulatory clinicians in Massachusetts (the United States) has modestly slowed ambulatory cost growth (Adler-Milstein et al., 2013).

40. A recent systematic analysis of the impact of technological change as captured by substitution of existing technologies found that two thirds of innovators have quality-adjusted prices that are higher – a median of 4% - than those of the previous existing technologies (Hult et al., 2018).

41. While case studies can explain the impact of certain medical advances on the cost (and benefits) of treating specific conditions, these studies cannot capture the effects of diffusion of new technologies in larger populations than those sampled, let alone for a panel of countries or indeed the impact on overall spending. External validity is therefore a concern for this kind of studies. Moreover, as explained above, even if the population of a country was fairly well represented, it would be hard to generalise the findings of such a study given the different behaviours observed at the aggregation level in itself.

3.1.2. Macroeconomic approaches: residual and proxy estimation

42. In the macroeconomic literature, two main approaches have been commonly used: the most common one in component-based models, following the macroeconomic insights of Solow (1957), is the residual approach; while the second one, mostly preferred in macro-level literature on the drivers of HCE growth, is what Chernew and May (2011) refer to as the affirmative approach, or put more simply, the proxy approach.

43. The residual approach uses regression methods to estimate the impact of time-varying drivers on health care expenditure growth, excluding any measure of technological change from the regression. The residual coefficient derived from the regression is then interpreted as an estimate that captures the impact of technology. This method is relatively straightforward, as it circumvents the need to specify a direct measure of technology and it is widely used in international comparative work (Holly et al. 2011; de la Maisonneuve and Oliveira Martins 2013).

44. In fact, this method is particularly sensible to endogeneity issues, arising from interactions among health expenditure determinants. Any estimate based on the attribution of a residual after accounting for other factors will be sensitive to the identification of factors contributing to growth as well as the numerous assumptions necessary to evaluate the role of each factor. In addition, these estimates convey no information as to the nature of the process through which technology progress influences expenditure.

45. Moreover, the residual method is also endogenous with respect to misspecification of the health expenditure determinants equation. Therefore, it captures not only technological impact, but also the impact of all other variables and trends that are relevant in explaining technological change but are not included in the equation.

46. The proxy approach, on the other hand, uses a suitable proxy variable to be included directly in the regression model. Such proxies are varied, and they are alternatively specified using both input (e.g. spending on research and development, spending on research by hospitals) and output measures (e.g. life expectancy, mortality rates, quality of care).

47. Using time fixed effects as a proxy assumes that scientific discoveries and diffusion of innovations progress smoothly with time (Okunade, 2004). A drawback of using year dummies is that they will capture the effect of influences in addition to technological change on health expenditure that are not directly controlled for such as government policy shifts as well as changes in public expectations, preferences and expenditure inertia (Di Matteo 2005). An advantage of capturing technology using time fixed effects rather than a residual is that the time-variant unexplained trends are correctly accounted for in the model.

48. Finally, some studies embed technological progress into the income elasticity coefficient value as the impact of technological change and income growth on health expenditure are inherently interrelated. Hall and Jones (2004) show that health expenditure growth will occur when rising incomes (and preferences that accommodate rising health share) are accompanied by advances in medical technology.

Table 3.1. Main features of the different approaches used to estimate the impact of technological change on health spending

Level of analysis	Methodology	Advantages	Limits
Micro	Case studies on cost (and benefits) of specific technologies, procedures, diseases and conditions	Potential for rigorous assessment of the impact on expenditure of specific technologies	Sampling bias. Difficulty in generalisation of results
Meso	Econometric analysis of the links between a specific cluster of technologies (e.g. pharmaceuticals) or technological progress at provider level (e.g. hospitals) and health expenditure	Potential for sound partial assessment of the impact on expenditure of clusters of technologies	Difficulty in generalisation of results
Macro	Econometric analysis, residual approach: estimation of the impact of main determinants – e.g. income, change in the structure of the population and its health status – on health expenditure and residual attribution of unexplained expenditure growth to technological progress	Incorporation of technological change in full (no limitation in representation as in case studies)	No identification of the effect of single technology components; impact of technological progress overestimated in the likely event of mis-specification of all other determinants (endogeneity)
	Econometric analysis, proxy approach: analysis of determinants - including technological change - of health expenditure	Rigorous assessment of significance and magnitude of impact	Need to represent technological change though measurable proxies that might alter its representation (or not capture its effect fully)

Source: Adapted from Pammolli et al., 2005.

3.1.3. Meso level or mixed approaches

49. Approaches at meso level look at the links between a specific cluster of technologies (e.g. pharmaceuticals) or technological progress at provider level (e.g. all technologies adopted by hospitals) and health expenditure.

50. Similar to microeconomic approaches, findings from those studies cannot be generalised at the health system level. However, those studies focus on goods or providers that account for a significant share of health expenditure. Hence, results of these studies may provide policy makers with sound information and insight.

51. An overview of the advantages and limitations of the main methods used to assess the impact of technological progress on health expenditure is reported in table 3.1.

3.2. Panel data estimation for health expenditure drivers

52. A number of studies have used econometric techniques to quantify the impact of determinants of health expenditure (not necessarily including technology). Early papers, like Getzen (1992), regressed health expenditure against its likely determinants across countries and time. However, Hansen and King (1996) argue that the results obtained in these studies 'may be misleading, or even completely spurious' because most of the variables included in the models are non-stationary, thus violating one of the key assumptions of ordinary least squares regression. Moreover, most studies before the early 2000s were mainly conducted on cross-sectional data or pooled across years, biasing the results for the models.

53. Recent papers have applied modern time series techniques — in particular, unit root testing, cointegration and error correction models — to health expenditure data (for example, Murthy and

Ukpolo 1994; Blomqvist and Carter 1997; McCoskey and Selden 1998; Roberts 1999; Gerdtham and Löthgren 2002; Herwartz and Theilen 2003). The determinants of health care expenditure considered in these models include: GDP; the relative price of health care; the percentage of public financing of health care; the number of practising physicians per head of population; and the share of people aged 65 + in the population.

54. Technology, often cited as a major driver of expenditure, is not explicitly a variable in these models. Current models (from 2005 onwards) have moved towards the following standard specification:

- The regression methodology (fixed or random effects) is applied to a panel of 20+ countries across as many years as possible;
- All data is transformed in its log differenced (instantaneous growth) form in order to take into account stationarity and cointegration issues;
- The dependent variable of reference is either public or total current health expenditure in real terms;
- GDP per capita is used to measure income effects;
- Population structure and size, together with measures of time-to-death through life expectancy, death rates and death-related costs, are used to measure demographic effects;
- Wages and productivity in the general economy, sometimes adjusted by the services share of labour in the total economy, or measures of medical prices, are used to measure the impact of the Baumol effect;
- The residual method, time fixed effects, R&D or patents proxies, are the methods most commonly used to measure the impact of technology.

55. Table 3.2 below summarises the most commonly used variables in models of HCE growth drivers.

Table 3.2. Drivers of health care expenditure and proxies used

Driver of HCE	Variables used in models
Ageing	Share of the elderly (65+), Share of the young (15-), Death-related costs and age-specific cost curves, Life expectancy
Baumol's cost disease	Medical prices, Wages and productivity (Baumol variable)
Income	GDP per capita
Technology	Index of hospital-country characteristics, Life expectancy, Infant mortality, Death rates, Share of R&D spending, Share of patents, Time trends, Residual estimation, Index of medical technology
Policies	Indexes of policies and institutional characteristics of countries, Health reforms

Source: Adapted from Marino et al., 2017.

4. Evidence from the literature

56. In this section, a review of studies from the literature is presented. These studies capture the impact of technology using a range of methods, proxies, samples of countries and levels of aggregation. Table 4.1 reports the main features and findings of studies that looked at the link between technology at function/provider level and health expenditure, whereas Table 4.2 shows the results of studies that use a "residual" or "proxy" approach.

57. Results from Table 4.2 show the relative contribution of the technological proxy to total health expenditure. Given the important differences in methods, proxies and presentation of results, a degree of harmonisation is required in order to present comparable effects. The last column to the right in Table 4.2 shows the relative contribution of technological change to health care expenditure growth. This allows converting results presented in coefficient form into a relative contribution by summing the coefficients for all drivers in the regression and estimating the share of the technology coefficient(s) by itself. Whenever available, a range is presented, otherwise the value reflects the preferred specification of the author (s). Values marked by an asterisk are estimates of the share of contribution derived from the coefficients presented in the study, while those without an asterisk show the contribution estimated directly by the author(s) of the study.

Table 4.1. Selected studies on the impact of technology at function/provider level

Author	Year	Country	Period	Method	Function/provider	Effect	Comments
Bundorf et al.	2009	United States	2001-2006	Proxy	Outpatient, pharmaceutical		Time effect
Blank and Van Hulst	2009	The Netherlands	1995-2002	Proxy	Hospital	ICT: cost saving Hospital transferred care: cost increasing	Index of innovation
Acemoglu	2013	United States	1970-1990	Proxy	Hospital	>50%	Time effect
Thiébaut, Barnay and Ventelou	2013	France	To 2029	Markov micro-simulation model to forecast future national drug expenditure	Reimbursable drug expenditure (except OTC and hospital)	For the population aged 25+, increases in reimbursable drug expenditure of 1.1% - 1.8% (annual growth rate)	Sample from the French household survey
EvaluatePharma	2017	Global	2018-2022	Integrated multiple consensus forecasts by equity analysts with historic results, as reported by companies	Global prescription drug sales data, with a split for generics, orphan and other 15 therapeutic areas	Global prescription drug sales forecasted to grow at 6.5% (CAGR) through 2022	
Espin et al.	2018	France, Italy, Germany, Spain, United Kingdom	2017-2021	Forecasts	Pharmaceutical sales at retail prices (outpatient and inpatient)	Projected AAGR for 2017-2021 at resp. list and ret price: France: 1.8% and 0.6% Germany: 3.2% and 2.0% Italy: 3.2% and 1.1% Spain: 2.5% and 1.1% UK: 3.8% and 2.3%	
IQVIA (formerly Quintiles-IMS)	2018	Global, regional and by country (US, EU5, Japan, Canada, Australia, South Korea and some 'pharmemerging' markets)	2018-2022	Annual projections of market trends	Global prescription drug sales data, split by region, by market segments, by therapeutic class and by type of product	The global pharmaceutical market is projected to increase by 3–6% annually at constant prices between 2018 and 2022.	

Table 4.2. Selected studies on the impact of technology at the macro level

Author	Year	Country	Period	Method	Variable	Income	Baumol	Demography	Effect
Okunade and Murthy	2002	United States	1960-1997	Proxy	Total and health-specific R&D spending	Yes	No	No	10-26%*
Freeman	2003	United States	1966-1998	Proxy	Time effect	Yes	No	No	27-37%*
Di Matteo	2005	United States, Canada	1975-2000	Proxy	Time effect	Yes	No	Yes	60-65%
Dreger and Reimers	2005	21	1975-2001	Proxy	Life expectancy, infant mortality	Yes	No	No	70-75%
Smith et al.	2009	United States	1960-2007	Residual proxy	Time effect	Yes	Yes	Yes	27-48%
Frogner	2010	United States, Australia, Canada	1970-2005	Proxy	Human capital	Yes	Yes	Yes	Positive
Narayan et al.	2011	18	1972-2004	Proxy	Time effect	Yes	Yes	Yes	Positive
Holly et al.	2011	143	1995-2008	Proxy	Time effect	Yes	No	Yes	Positive
Farag et al.	2012	174	1995-2006	Proxy	Time effect	Yes		Yes	15%+*
Colombier	2012	20	1965-2007	Proxy	Pharma R&D, life expectancy, infant mortality, death rate	Yes	Yes	Yes	20%*
Wong et al.	2012	Netherlands	1981-2009	Proxy	Patent numbers	Yes	Yes	Yes	Non-linear across age
Ho et Zhou	2014	China	2002-2010	Proxy	Health quality index	Yes	Yes	Yes	5-10%*
Willemé and Dumont	2015	18	1981-2012	Proxy	Number of approved medical tech	Yes	No	Yes	37%
Zortuk and Ceken	2015	11	1995-2011	Proxy	Time effect	Yes	No	Yes	Positive
You and Okunade	2017	Australia	1971-2011	Residual proxy	Index of technology	Yes	No	Yes	35-40%*
Cinaroglu and Baser	2018	14	1990-2011	Proxy	Patent numbers	No	No	No	High corr.

Note: (*) estimates of the share of contribution derived from the coefficients presented in the study.

4.1. Findings from "case studies"

58. As an example of case study approach, Cutler and McClennan (2001) estimated the cost (and benefits) of technological change for five conditions: heart attacks, low-birthweight infants, depression, cataract surgery and breast cancer. The introduction of coronary care units and bypass surgery – both landmark medical innovations – added 33% to the treatment cost of acute myocardial infarction (AMI). Similar increases were also observed with the introduction of caesarean sections for childbirth.

59. However, the impact of "little ticket" technologies – those with low unit prices but broad application (e.g. lab tests; X-rays) – has also been considerable (Scitovski, 1985; Scitovski and

McCall, 1976). Importantly, the introduction of many technologies that enabled treating a specific pathology more efficiently (with fewer inputs) has resulted in an increase in aggregate expenditure, as providers responded to the surplus capacity by treating more cases. Laparoscopic cholecystectomy, which enabled the procedure to be conducted as a day-case not necessitating an overnight hospital admission, is a good example (Legorreta et al., 1993; Steiner et al., 1994).

60. On the other hand, preventive technologies such as vaccines have resulted in dramatic reduction in costs through a reduction in illness and care avoided down the line. In most cases, however, technologies have been additive rather than substitutive in existing clinical practice (Showstack et al., 1982), thus placing upward pressure on expenditure growth. Studies examining a range of clinical specialty areas found that those with greater adoption and use of new technologies, such as cardiology and orthopaedic surgery, exhibited greater spending growth (Holahan et al., 1990).

4.2. Results from studies that use the "residual" approach

61. Smith et al. (2009) provide an extensive analysis of the impact of technology using the residual method. They run a fixed effects model that includes income effects, demographic effects, the Baumol effect, and changes in insurance coverage. Technology is modelled both by using time fixed effects and by estimating a residual, which includes the interaction of income elasticity and technology. They find that technology accounts for 48% of all HCE growth, 27% of which is endogenous to income effects. Therefore, the pure technology residual is estimated at 26%.

62. De la Maisonneuve and Oliveira-Martins (2013) also project technology through a residual component, after accounting for income effects, health status and demographic effects (with different hypotheses about healthy ageing). They find that HCE will grow by a residual 1.7% per year in their most pessimistic scenario, and by 0.8% in their most optimistic one.

63. A similar approach to the residual model, which relies on a specific macroeconomic assumption, was theorised by Geay and de Lagasnerie (2013). Their approach is to embed technological progress into the coefficient for income elasticity by increasing its value exogenously. They assume that income elasticity is 1.3 at the beginning of the projections period and converges linearly to 1 at the end of the projection period (2060). In their sensitivity analysis, they show that the assumption on technological progress results in an increase of 1.1 percentage points in health expenditure as a share of GDP at the end of the projection period (from 10.4% to 11.5%).

64. This assumption is akin to a residual model, where an exogenously determined coefficient is applied to what we call technology. However, linking elasticity of income and elasticity of technology does not solve the endogenenity issue – in fact, when a single elasticity is used, we cannot properly capture what happens in projections as one driver (e.g. GDP for income elasticity) increases as another (e.g. technological change) decreases, since they are both embedded in one coefficient.

65. The assumption that income elasticity is a luxury good might be better suited to individual level studies, where health as a good is indeed a luxury, and therefore better technology available will increase individuals' allocation of expenditure to health over time.

66. This finding is echoed in Farag et al. (2012), who estimates a model with and without year fixed effects, and finds elasticity of income to be below one with time fixed effects, but above one without. This indicates that there are indeed year-effects independent of income, and the most likely explanation of the time-specific variation is that there are changes in technology over time, and year dummies may well capture this trend. By subtracting the estimated impact of dummy year effects (elasticity above one) from the elasticities measured from regressions without year effects, we can estimate an impact of technological change of around 20% of total contributions to HCE.

4.3. Findings from studies that use the "proxy" approach

67. Di Matteo (2005) was one of the first studies to assess the impact of time effects on a panel data sample for the United States and Canada. Regressing real per capita health expenditures on age distribution, income, province/region specific indicators and time, he finds that, once technological change is accounted for, ageing and income explain a relatively small proportion of expenditure

variation. In the study, time explains approximately two-thirds of the increase in health expenditure. Time effect represents an upper bound estimate of the impact of technology on health expenditures as they can also encompass the effects of policy shifts, omitted variables, changes in preferences and expectations.

68. Similarly, Blomqvist and Carter (1997) adopt a linear time trend to account, at least in part, for the impact of technological change on health expenditure. Using annual data across a cross section of OECD countries, they find that technological change (proxied by the time trend) accounts for 2 percentage points of the annual growth in real health expenditure.

69. Okunade and Murthy (2002) use total US research and development (R&D) and US health sector R&D expenditure as proxies for technological change. They find evidence of a stable long run (co-integrated) relationship between real US health expenditure per capita, real GDP per capita and technological change in the United States between 1960 and 1997. Dreger and Reimers (2005) adopt a similar approach, using three proxies for medical progress: life expectancy; infant mortality; and the percentage of the population older than 65. They find a cointegrating relationship between real health expenditure per capita, real GDP per capita and each of the technological change proxies across 21 OECD countries. The estimated contribution of total and health-specific R&D spending to HCE ranges between 10 and 26% of the growth share, with the remaining share being modelled by income effects.

70. A more recent study by You and Okunade (2017) explores proxies for technological change, including the residual approach, in a study for Australia: research and development expenditure, hospital research expenditure, hospital treatment coverage, share of the elderly (used in a similar way to life expectancy in other studies), infant mortality rate, and weighted and unweighted indexes of medical device technology. The rationale behind using the share of the elderly is that "changes in fertility rates and life expectancy (and consequently the share of the aged) might be influenced by technologies for improving longevity or delaying fertility".

71. After controlling for income and ageing used in different specifications as a proxy for demographics and technology, they find significant coefficients for all proxies. Predictably, the variable for R&D has sometimes a lower coefficient than a proxy like the medical devices index. This is because new medical devices can induce patient demand with a much shorter lag as compared to changes in health care expenditure due to changes in the expenditure on R&D. This suggests that the R&D variable could be introduced with a lag in the model to take into account the hypothesis that current health care expenditure is influenced by past increases of spending in R&D that may result in new technologies introduced only after several years.

72. You and Okunade (2017) estimate a technology effect of 0.349 on the growth of Australia's HEXP using the residual component approach. The technology effects for Australia based on the proxy approach range from 0.15 to 0.56. The technology coefficients for the R&D expenditure, hospital research spending, and the unweighted technology index are 0.329, 0.353, and 0.335, respectively. These coefficients sum up to around 35-40% of the total share of HCE growth.

73. Willemé and Dumont (2015) provide another interesting take on proxying for technological change by looking at the number of approved medical technologies across 18 OECD countries. Their proxies include the number of new drug applications (NDAs), the number of new chemical structures (NMEs), the number of pre-market approvals (PMAs) and the number of pre-market notifications (PMNs). Their model is a panel regression run on income, lifestyle changes (proxied by BMI growth), and the aforementioned technology proxies, tested for a series of lags. They find that the impact of technological change varies between 18 and 57% across different specifications, with the average contribution being 37%.

74. A recent projection effort by the OECD (Lorenzoni et al., 2019) uses time fixed effects to extrapolate technological change in a panel regression run across all 35 OECD countries for the years 1994-2015. The model also includes a proxy for technological change in the form of growth of R&D spending in the general economy with 5-year lags, and the common drivers for income, demography and the Baumol effect. The estimated contribution of technology on HCE growth is of 11-15% of total annual growth.

4.4. Results from studies on pharmaceuticals and hospitals

75. Medicines – part of biomedical technology – account, on average, for one fifth of current health expenditure across OECD countries. Two systematic reviews (Mousnad et al. 2014; Karampli 2014) identified changes in utilisation, (mix of) therapies and prescribing choices as well as new drugs availability as key drivers of pharmaceuticals expenditure.

76. A recent survey carried out by the OECD (2019) confirmed that short-term projections of pharmaceutical expenditures are not straightforward as they would require information on past trends, ideally at product level, and make assumptions about future market dynamics (e.g. new products, products going off patent) which are not usually available.

77. Historical expenditure patterns and changes in demand side factors have been identified as the main drivers of medium to long-term projections of pharmaceutical spending. As an example, the expenditure for reimbursable drugs in France is expected to grow between 1.1% - 1.8% on an annual basis up to 2029 (Thiebaut et al. 2013), whereas in the United States prescription drug spending is expected to increase, on average, by 6.1 percent per year for 2020–27 (Sisko et al. 2019).

78. Short-term (1 to 5 years) projections are more readily influenced by supply-side movements and market dynamics. Current estimates to 2022 forecast worldwide prescription drug sales to grow by 3-6.5% annually (EvaluatePharma 2017; IQVIA et al., 2018), the orphan drug market to almost double between 2016 and 2022, and sales of anti-diabetic and oncology drugs to grow annually by 7% and 13% respectively (EvaluatePharma 2017). Espin and colleagues (Espin et al., 2018) found a pharmaceutical expenditure growth rate of 1.5% - after adjusting for discounts and rebates - for France, Italy, Germany, Spain and the United Kingdom from 2017 to 2021.

79. Blank and Van Hulst (2009) studied the relationship between technology and cost in Dutch hospitals from 1995-2002. They clustered primary types of technological innovation into seven groups (multidisciplinary diagnostics and treatment; technical (medical) quality; nursing consulting hours; chain care; logistic optimisation; hospital transferred care; and information and communication technology) and found that information and communication technology is the only significant cost saver cluster.

80. Acemoglu et al. (2013) explore the relationship between hospital expenditure, income effects and income-induced innovation using oil prices as a proxy to control for general equilibrium effects in regions across the United States. This methodology incorporates endogenous technology effects into the income component, with an elasticity that reaches 1.13.

5. Discussion

81. Measurement of the impact of technology as a driver of health care spending is complex given its highly endogenous nature. A major difficulty is that technological progress, broadly defined, is not directly observable. Some partial measures are available — new pharmaceuticals, for example — but these do not capture the full impact of technological change on overall health spending.

82. Two approaches attempt to by-pass this problem: the residual approach — which quantifies the impact of other determinants of health expenditure and attributes the unexplained component to advances in medical technology; and the proxy approach — which specifies a proxy measure for technology.

83. The limitations of these approaches - particularly their sensitivity to the choice of other determinants of health expenditure to be taken into account and their focus on the aggregate impact of technology that can obscure the ways in which individual technologies have affected health care expenditure — should be kept in mind when considering the results.

84. Both approaches provide support to the finding that technological progress has been an important driver of the growth in health expenditure. The estimated impact of technology in terms of its relative contribution to health care expenditure growth ranges significantly across studies – from 10 to 75% of total health expenditure growth. Some of these studies are unable to capture the endogenous effects between income and technology (or indeed, other drivers), but generally most of the values are concentrated between 25 and 50% of yearly growth. The unweighted average of the shares presented in our summary table is 35%.

85. Applying this contribution to historical growth rates across OECD countries (1995-2015), we can estimate a historical contribution of around 1% yearly health care expenditure growth[3]. Looking at projections in the next decades, health expenditure is projected to grow at a slightly lower pace compared to the previous period, with 2.7% estimated yearly growth (Lorenzoni et al., 2019). On average, this would mean a contribution of 0.9% per year to total health expenditure coming from technological change.

86. Several "mechanisms of action" through which technological progress affects health care spending have been identified:

- new product (e.g. a new pharmaceutical) or equipment that allows a new service to be provided (e.g. mobile health applications);
- full or partial substitution for current approaches (e.g. laparoscopic techniques to substitute for the traditional open procedures);
- increased use of pre-existing services also by expanding the indications for a treatment (e.g. prostate cancer screening leading to more prostatectomies);
- development of treatments for conditions once regarded beyond medicine boundaries, such as mental illness and substance abuse; and
- life-extending effect of new technologies, for which each survivor will generally consume additional health care goods and services over their now longer life.

87. The impact of technological progress on health expenditure is also a function of the policy context and the broader institutional context governing the adoption of new technologies — for example, the use of health technology assessment. Hence, the impact of the supply of advances in technology on health expenditure cannot be considered in isolation from demand and policy

[3] The historical yearly growth rate was 3% across the OECD for the period 1995-2015, with an estimated 35% coming from technological progress.

influences. It is the interaction of supply and demand factors that determines the ultimate level of spending and technology use (Australian Government Productivity Commission 2005).

88. Importantly, very few of the studies reviewed estimate the quality gains that technology brings. An understanding of these gains both in terms of benefits within the health system and outside (e.g. its impact on life expectancy, ageing populations, productivity and GDP) will allow having a fuller picture of the impact of technological progress on health outcomes, which is what ultimately matters.

89. Therefore, more research is needed to shed light on the link between technological progress, its uptake, quality of care, demand and supply side features and health expenditure. Better data and longer time series would allow identifying sound proxies of technological progress, which may be used to further analyses. A crucial step forward would be to theorise a framework where all the monetary costs (and benefits) of better quality of care are captured into the equations for health expenditure drivers.

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