THE INFLUENCE OF EXPERIENTIAL LEARNING ON MEDICAL EQUIPMENT ADOPTION IN GENERAL PRACTICES

Abstract

The benefits of the availability and use of medical equipment for medical outcomes are understood by physicians and policymakers alike. However, there is limited understanding of the decision-making processes involved in adopting and using new technologies in health care organisations. Our study focuses on the adoption of medical equipment in Irish general practices which are marked by considerable autonomy in terms of commercial practice and the range of medical services they provide. We examine the adoption of six items of medical equipment taking into account commercial, informational and experiential stimuli. Our analysis is based on primary survey data collected from a sample of 601 general practices in Ireland on practice characteristics and medical equipment use. We use a multivariate Probit to identify commonalities in the determinants of the adoption. Many factors, such as GP and practice characteristics, influence medical equipment adoption. In addition, we find significant and consistent evidence of the influence of learning-by-using effects on the adoption of medical equipment in a general practice setting. Knowledge generated by experiential or applied learning can have commercial, organisational and health care provision benefits in small health care organisations.

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1: Introduction

Almost fifty years ago, Kenneth Arrow declared that virtually all the special features of the medical care sector stem from the prevalence and extent of uncertainty [1]. This uncertainty relates to both the occurrence of disease and the efficacy of treatment. While health care outcomes are dependent on a range of factors, physicians face strong clinical, economic and social incentives to adopt and use new technologies in the prevention and treatment of disease [1, 2]. Across Europe, it is within primary care that patients normally enter the health care system, where the scope of patients' health problems is first examined, and where referral decisions are made [3, 4]. Previous studies have shown that general practitioners (GPs) with better access to diagnostic tests more appropriately diagnose, refer and treat patients [5]. There is also evidence that the presence of medical equipment in practices positively influences medical outcomes [6], as well as impacting on patients' satisfaction [7]. While the benefits of the availability and use of medical equipment to medical performance are understood by physicians and policymakers alike, there is a need for greater understanding of the decision-making processes involved in adopting and using new technologies in health care organisations.

Our study focuses on the use of medical equipment in Irish general practices. Irish GPs are by and large self-employed private practitioners who choose their practice premises, who they employ and how much they charge for consultations and any additional services they provide [8, 9]. Irish GPs treat private patients who pay directly on a fee-for-service basis, and public patients who attend their GPs free of charge and for which GPs are reimbursed on a capitation basis by the State. Ireland is identified as one of the European countries where GPs are predominately the first point of contact with health care services [3]. Therefore, Irish GPs provide a comprehensive mix of services, in fact, to a greater extent than many of their European counterparts [3]. The commercial autonomy and gate-keeper features of Irish general practice provide an interesting context for our analysis.

The independent decision-making afforded Irish GPs in terms of how they equip their practices and the range of medical services they provide suggests that decisions to invest in medical equipment will reflect both medical and commercial factors. Acquiring new medical technologies may enable GPs to provide more effective treatment to their patients [5, 6], but may also influence their attractiveness to mobile and commercially valuable private and public patients [7]. Therefore, we draw on a body of literature that examines the adoption of new technologies through the lens of commercial, informational and experiential stimuli. This theoretical framework has largely been applied to technology adoption by businesses [10-14], although more recently it has been applied to the adoption of health care technologies, such as, an examination of the adoption of hospital information systems (IS) in the United States (US) [15] and the adoption of new prescription drugs by Irish GPs [16]. Survey data provides us with information relating to practice characteristics and the adoption of medical equipment for a sample of 601 general practices in Ireland. Our empirical approach applies multivariate Probit analysis to identify commonalities in the determinants of the probability of use of such equipment.

The paper is organised as follows. Section 2 outlines our conceptual view of the adoption of medical equipment and reviews previous empirical studies of the adoption and use of medical equipment by GPs. Section 3 describes our primary data source, presents diffusion curves for the items of medical equipment examined, and outlines our econometric approach. Section 4 presents and discusses the econometric results, and Section 5 concludes.

2: Conceptual Framework

Our unit of analysis here is the general practice, and our focus is on the factors which influence the adoption of medical equipment. The health economics literature frequently profiles GPs as economic agents who respond to economic incentives and are aware of the competitive structure of their environment [17, 18], indicating the potential for commercial motivations to influence practice development decisions. Irish GPs, in particular, operate as self-employed, private health care practitioners suggesting that their investment and practice development decisions will be shaped by both pecuniary (income generation) and non-pecuniary (health care service provision) factors. In more formal terms we might therefore argue that Irish GPs seek to maximise a utility function (U) that is increasing in the expected returns from their practice (π), and the non-pecuniary value which they place on service delivery (S), i.e.

$$U = \beta_1\pi + \beta_2 S. \quad (1)$$

Where β_1 and β_2 are weights reflecting GP's relative valuation of pecuniary and non-pecuniary benefits. In this framework GPs will chose to invest in new medical equipment and services when their utility post adoption (U_{t1}) is greater than their utility pre-adoption (U_{t0}).

$$U_{t1} - U_{t0} = \beta_1(\pi_{t1} - \pi_{t0}) + \beta_2(S_{t1} - S_{t0}) > 0 \quad (2)$$

Assuming that any new adoption has no implications for other revenues or services provided by the GP, the change in practice profits as a result of any new service will be the difference between the new revenues generated (R_{t1}) less the costs (C_{t1})[1], i.e.

$$\pi_{t1} - \pi_{t0} = R_{t1} - C_{t1} \quad (3)$$

Therefore, in estimating the change in utility as a result of investing in any new service, GPs will consider the expected new revenue generated, the expected costs incurred and the anticipated improvement to service delivery

$$U_{t1} - U_{t0} = \beta_1(R_{t1} - C_{t1}) + \beta_2(S_{t1} - S_{t0}) \quad (4)$$

Notably each of these elements of the GP's decision making rule will depend on the characteristics of different GPs, their adoption decision-making to date and their connectedness with others. Different GPs, for example, may place very different weights on the non-pecuniary evaluations of the value of any new service provision. Or, because of their market or geographical position, they may generate very different revenue streams from any given service. Early adopters may also be able to charge more for a unique service, and may also benefit from greater non-pecuniary benefits if they are able to help a group of patients for the first time. As adoption becomes more widespread, service charges, and potentially the associated non-pecuniary benefits, may also decline. Equipment costs are also likely to fall as adoption becomes more widespread, potentially changing GPs' cost-benefit calculations.

Reflecting these individual and environmental factors three complementary approaches have been used to explain the timing of adoption of new equipment or technologies. First,

[1] It is worth noting, however, that the cost of any service change may also include non-monetary costs such as the time and effort that the change necessitates. We ignore any non-pecuniary costs of service change here.

disequilibrium models reflect the learning and informational influences on adoption decision-making [19]. Second, equilibrium models take account of how organisational characteristics and strategic interactions influence the returns from adoption [10]. Within the equilibrium model, rank effects assume that the different inherent characteristics of potential adopters influence the returns obtained from the adoption decision.[2] Third, learning-by-using models reflect cumulative learning experience from previous adoption decisions influencing adoption [20].

Next, we discuss how we expect, *a priori*, equilibrium, epidemic and learning-by-using effects to influence GP's utility functions and consequently their adoption decisions concerning the use of medical equipment. Some practices due to their size and composition will have greater ability to exploit the benefits from adoption. Therefore, we expect that rank effects will positively influence post-adoption utility, and these practices being in a position to increase revenue and improve service delivery, with the cost of adoption being negligible due to their size and composition. Previous studies have found evidence in support of the influence of rank effects on adoption decision-making in health care organisations. McCullough [15] finds that adoption of IS in US hospitals is driven by variation in hospital characteristics and Bourke and Roper [16] report that GP and practice characteristics positively influence the adoption of new prescription drugs by Irish GPs. Although previous studies do not specifically examine medical equipment use by general practices they highlight how support staff and practice size directly and indirectly influence the use of medical equipment in UK and European general practices [21, 22]. As Irish GPs are assumed to maximise utility functions that are increasing in profits and service delivery we expect rank effects to positively influence the use of medical equipment in Irish general practices.

Epidemic effects assume potential adopters who interact with those who have already adopted are themselves more likely to adopt. In relation to the GP utility function, the

[2] In the innovation literature, stock and order effects capture strategic behaviour [10-14]. Specifically, the stock effect assumes that as the stock of adopters increases, the marginal benefits from adoption declines. In this study, given the cross-sectional nature of our survey data, we are unable to construct a stock effects variable, which is a time-variant measure of the stock of previous adopters. Order effects capture how potential adopters are influenced by the adoption decisions of co-related agents as those higher in the adoption order obtain greater returns from adoption. However, any order effect variable would be highly correlated with the cumulative length of use (learning-by-using effect) variables. In addition, a previous study of prescribing adoption discussed how order effects may be capturing information flows and learning within a health care setting [16]. Therefore, we do not include order effects in our model.

knowledge acquired by connected GPs ensures increased revenue, reduced costs and improved service delivery with respect to the adoption decision. Previously, Bourke and Roper [16] reported that rural GPs in Ireland are slower to prescribe new drugs and a UK study reported that training practices are more likely to have a broader range of equipment than their counterparts [23]. In line with the epidemic effect hypothesis, McCullough [15] reports that multi-hospital systems in the US are earlier adopters of IS.[3] Therefore, we expect that epidemic effects will have a positive effect on medical equipment adoption by general practices.

Learning-by-using effects capture the influence of experiential knowledge on adoption decision-making. It is likely that practices that have compiled a portfolio of medical equipment over time will exploit this knowledge to ensure that they increase revenue, reduce adoption costs and improve service delivery in subsequent adoption decision-making. Therefore the number of years that practices have been using a portfolio of medical equipment will impact on their adoption decision-making. Practices with greater opportunities for such experiential learning – practice with more items of medical equipment over longer time periods - are more likely to adopt new items of medical equipment. While there is little empirical investigation of the influence of learning-by-using effects on adoption of health care innovations, Bourke and Roper [16] report GPs with broader prescribing portfolios as being early adopters of new drugs. We therefore expect learning-by-using effects to positively influence medical equipment use in Irish general practices.

3: Data and Methods

3.1: Data Source

Our empirical analysis is based on survey data, collected through a self-administered postal questionnaire -*Medical Equipment and IT in General Practice*- distributed to all general practices in Ireland in Spring 2010.[4] Designing a sample frame of all general practices in Ireland is complicated by the fact that there is no official register of Irish GPs [26].[5]

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[3] However, it is important to note that previous studies report a higher availability of medical equipment in rural practices regardless of the type of health care system [22,24] which may be indicative of a 'compensation' effect, whereby GPs provide services that are not available locally through the secondary care system.

[4] See Bourke and Bradley [24, 25] for a detailed description of the survey data.

[5] Under the Medical Practitioners Act (1978), it was not possible to distinguish GPs from other types of Medical Practitioner on the General Register [28]. A new Medical Practitioners Act (2007) requires GPs, as of March 2009, to register as a GP specialist [29]. Therefore, up to recently, it was difficult to determine exactly how many GPs are practicing in Ireland.

However, it is estimated that there are approximately 2,500 GPs in Ireland and approximately 1650 general practices in Ireland [4, 9, 26, 28]. The Golden Pages website, the Irish telephone directory for businesses, provided the sample frame for this study. Table 1(a) provides a description of the sample frame construction, which comprises of contact details for 1417 practices.

<< Insert Table 1 here>>

Response rates to postal surveys, especially among physicians, have been suboptimal; which has been attributed to increasing workloads and the low priority physicians place on survey completion [29]. Prior to administering the survey, we were advised that Irish GPs can receive a number of questionnaires every week. We received 601 completed questionnaires, representing a 42% response rate (see Table 1(b)). This response rate is in line with previous studies of physicians [30, 31] and surveys of innovation activity [32]. A Chi- Square Goodness of Fit test was conducted to determine if the responses by HSE region were representative geographically. There is slight over-response from the HSE South region; potentially as the survey was administered from University College Cork, located in the south of Ireland. However, the extent of over-response is small. For instance, if 11 fewer responses had been received from the HSE South, the sample would have been representative (see Table 1(c)).

It is estimated that there are approximately 1650 general practices in Ireland [9, 28]. Therefore, we estimate that a sample size of 601 represents a third of the general practices in Ireland. Our data was specifically collected for this empirical investigation and contains information concerning practice structure, support staff, educational and training activities, clinics, and use of medical equipment and ICT [24, 25]. However, there is always the potential for self-selection bias with a self-administered questionnaire, and we ought to assume that some respondents to the survey are those GPs that are interested in equipment provision and investment in general practice. Furthermore, self-reported data can result in socially desirable responding.

3.2: Description of Survey Data

Six items of medical equipment, identified as playing a significant role in GP's service provision from previous survey instruments, empirical literature and interviews with Irish GPs, were included in the questionnaire: ECG machines, 24 hour blood pressure monitors, spirometers, cryotherapy equipment, minor surgery equipment, and foetal monitors.[6] These items of equipment are used to diagnose, monitor and treat different therapeutic conditions and their inclusion in the analysis should eliminate any potential inter-relationships between adoption patterns which might stem from individual GPs having a particular interest in a certain therapeutic area or medical condition. These items of medical equipment are widely available and used in general practices, although given the autonomy of general practices in Ireland their use and adoption is not uniform. Respondents were asked if their practice has each item of medical equipment and the year in which it was obtained. The adoption patterns for these six items of medical equipment are presented by means of diffusion curves [19, 33].[7]

<<Insert Figure1 here>>

Our survey results clearly indicate that a high proportion of Irish general practices now use these items of medical equipment. All six diffusion curves depict similar patterns, with low levels of adoption initially, followed by a 'take-off' in adoption rates, and eventually a levelling off as fewer non-adopter practices remain.[8] An earlier publication using this data source presents initial results in relation to equipment use by practice type:, indicating (i) a lower penetration of medical equipment among solo-practitioner practices than group practices; (ii) practices which invest in nursing support are also more likely to invest in medical equipment; and (iii) no relationship between HSE Region and possession of medical

[6] An ECG or electrocardiogram machine records the electrical activity of the heart; a 24 hour Blood Pressure Monitor is a portable battery-operated device, which continuously records a patient's blood pressure throughout the day and night over and expired by the lungs, thus assessing pulmonary function; a spirometer is a device for measuring flows and volumes inspired and expired by the lungs, thus assessing pulmonary function; cryotherapy is the application of extreme cold, usually in the form of liquid nitrogen, to destroy abnormal or diseased tissue, such as warts, moles and skin tags; a minor surgery kit contains the instruments necessary for minor surgical procedures; and ultrasound and Doppler foetal monitors are used to monitor a foetus' heartbeat and detect foetal abnormalities in prenatal care.

[7] Diffusion results from a series of individual decisions to begin using the new technology, i.e. to adopt the new technology [19]. The Diffusion of Innovations theory purports that when the number of adopters of a new product or technology is plotted on a cumulative frequency basis over time, the resulting distribution is an S-shaped curve [19].

[8] In these graphs, there appears to be a sharp increase in the adoption of all six items of medical equipment in the year 1990. This is an artefact of the data collection process. A small number of respondents provide answers such as 'circa. 1990' or '20 years ago' when asked the year their practice obtained each item of equipment.

equipment, with the exception being increased ownership of ECG machines for practices in the HSE West [25].

It is important to note that the practice characteristics obtained in our survey relate to the practice in 2010 and may vary substantially from the date the equipment was obtained. As a result, dynamic analysis of the adoption of medical equipment is not feasible. Instead, a cross-sectional analysis of the determinants of the use of medical equipment by general practices is more appropriate. Therefore, the dependent variables in our analysis will be binary in nature, taking a value of one if the equipment is present in the practice and zero otherwise.

In equilibrium models of adoption, rank effects are measured by a number of practice and GP variables. These variables are included in our model to identify which practice characteristics influence medical equipment adoption. On average there are 2.7 GPs per practice. The average number of patients is 4218 (log = 8.072), and on average 37% of those patients are public patients. These two variables also provide an indication of the market environment and opportunities within which the GP's practice is operating: the number of patients reflects the balance between the demand and supply of primary healthcare provision in the locality; the proportion of public patients is an indication of the revenue potential from that local demand. Nursing and administrative support are reported in 81% and 91% of practices respectively. Two dummy variables were created for the GP age and gender profile of the practice. In 25% of practices, all GPs are 40 years or older. In 51% of practices, there are more male than female GPs.

<<Insert Table 2 here>>

In disequilibrium models of adoption, epidemic effects reflect the impact of information flows on adoption. We measure these effects by practice location. We categorise practices as city (31.5%), town (50%) or rural (18.5%) practices. With respect to administrative region, there are four Health Service Executive (HSE) regions in Ireland. The HSE is responsible for delivering health care for the population of Ireland. Previous studies have reported HSE West practices as being more progressive with regard to practice equipment and IT use, perhaps to compensate for poorer access to secondary care services [25, 34, 35]. Therefore, we include a HSE West variable which accounts for 26% of practices.

Epidemic effects are also measured by whether the practice is a training practice (29%), holds a clinic delivered by a health care professional (29%), and how often it is visited by suppliers of medical equipment. We also include a variable which measures professional and academic involvement (70%). This variable takes a value of one if respondents are involved in at least one of the following: a committee member of a professional organisation, affiliated with an academic institution, involved in research projects, and completed/completing an Irish College of General Practitioners (ICGP) course or its' equivalent.[9] Attendance at Continuing Medical Education (CME) meetings, i.e. continuing professional development training for GPs in active general practice, was also recorded.

To model learning-by-using effects, six length of use variables were created. Each of these variables measures the (log of) the cumulative length of use of five items of medical equipment. For example, when analysing ECG adoption we include the (log of) the cumulative length of use of the other five items of medical equipment to model learning-by-using effects. These variables capture practices' experience with medical equipment and therefore the opportunity to learning from using such equipment over time.

3.2: Empirical Approach

Previous econometric studies examining technology adoption have employed duration analysis [11]. Duration, or failure-time, analysis focuses on the factors which determine the probability that a household or a firm will adopt a new technology by a specific point in time, and also allows researchers to model the S-shaped diffusion curves discussed earlier. However, duration analysis requires panel data. Given the cross-sectional nature of our data, we focus on the determinants of the probability of a practice using these items of medical equipment, rather than time to adoption. McWilliams and Zilbermanfr [20], also using cross-sectional survey data, attempt to overcome this constraint by employing a tobit model. In their study, the dependent variable takes a value of zero for non-adopters and a positive value, which is the number of years since first adoption, for the adopters. Their survey

[9] The Irish College of General Practitioners (ICGP) is the professional body for general practice in Ireland. It is the recognised body for the accreditation of specialist training in general practice in Ireland and is recognised by the Medical Council as the representative academic body for the speciality of general practice.

instrument determines the time of adoption of a new technology, if adopted, and both adopter and non-adopter characteristics. However, the implicit assumption of this approach is that individual characteristics do not differ from when the technology was adopted and the present, when these characteristics are documented through the survey process. This raises questions about the direction of causality as adopter characteristics may change following the adoption of a new technology. Therefore, we do not employ such a technique as the adopter characteristics at time of adoption, in some cases decades prior to data collection, may differ fundamentally from the practice characteristics collected through the survey process in 2010.

As previously discussed, we consider the adoption decision as a binary process whereby a practice chooses 'use' or 'non-use'. Probit models are an appropriate estimation methodology to investigate the effects of explanatory variables on dichotomous dependent variables [36]. It would be possible to run six adoption regressions where the binary dependent variable (Y_i) takes a value of one if one particular type of medical equipment is adopted and zero if that specific medical equipment is not adopted. However, if it is believed that the decisions to adopt each item of medical equipment are correlated, then the multivariate Probit model which allows for this correlation is appropriate for jointly predicting these six choices on an individual-specific basis. In addition, the unobservable factors that influence the adoption of all six items of medical equipment are likely to be related. This regression technique allows for the unobservable individual-specific heterogeneity in the estimation procedure in order to ensure consistent estimates of the coefficients [36,p.931-933].

Given the likelihood that the random components of the six Probits for each item of medical equipment are correlated, we model the use of these six items of medical equipment using a multivariate Probit analysis. The dependent variables in the multivariate probit model are:

y_1 = 1 if practice has an ECG machine, 0 otherwise.
y_2 = 1 if practice has a 24Hr blood pressure monitor, 0 otherwise.
y_3 = 1 if practice has a spirometer, 0 otherwise.
y_4 = 1 if practice has cryotherapy equipment, 0 otherwise.
y_5= 1 if practice has minor surgery equipment, 0 otherwise.
y_6 = 1 if practice has a foetal monitor, 0 otherwise.

The coefficients are estimated using the Geweke-Hajivassilou Keane simulator for probabilities and a maximum simulated likelihood procedure. The need for the multivariate Probit – rather than a series of separate Probit models – is suggested by the estimated variance covariance matrix, as the statistically significant covariance coefficients illustrate that the error terms from each equation do vary together (see Table 3).

<<Insert Table 3 here>>

4: Results

Multivariate Probit regression models of medical equipment adoption are presented in Table 3 [37].[10] In interpreting the multivariate Probit estimates, we are restricted to interpreting the sign and significance of the coefficients [36].

<<Insert Table 4 here>>

4.1: Equilibrium Effects on Medical Equipment Adoption

In the model we represent potential rank effects using a series of variables reflecting the characteristics of general practices. Practice size positively influences adoption behaviour. The number of GPs in a practice is found to positively impact on the probability of a practice adopting three of the items of medical equipment and the (log of) the number of patients positively impacts on the probability of a practice adopting two of the items of medical equipment. Therefore, the more GPs in the practice, the more probable it is for the practice to have this equipment. Also, larger practices, with respect to the number of patients, are likely to be seeing patients with a greater variety of conditions and illnesses, and therefore may be more likely to see the need to invest in equipment to cater for their patients' needs.

A higher proportion of public patients negatively impacts on the likelihood of a practice having minor surgery equipment. Minor surgery often involves elective procedures which public patients are entitled to access in hospitals free of charge. Private patients are required to pay, directly or through their private health insurance providers, for elective procedures in hospitals. Therefore, practices with a large proportion of public patients may not consider a minor surgery kit an integral part of their service provision, as they can direct their public

[10] The multivariate probit model is estimated using the mvprobit command within Stata 11.See [37] for a good description.

patients to secondary care, either through Accident and Emergency (A&E) or as a referral to a consultant.

A practice which employs a nurse is more likely to adopt medical equipment. This finding is evident for three of the items of medical equipment, although it is statistically significant at the 10% level in two cases. Previous studies have also reported that nursing support positively impacts on the use of medical technologies [22] and prescribing of new drugs [16]. Findings in relation to administrative support are inconclusive. There is some evidence to suggest that practices dominated by older GPs (40 yrs+) and male dominated practices are more likely to adopt medical equipment.

4.2: Epidemic Effects on Medical Equipment Adoption

In the multivariate Probit model, we also examine the influence of epidemic effects on adoption decision-making. There is little evidence that practice location with respect to rural-urban classification has much impact on adoption decision-making, although town practices are more likely to adopt a foetal monitor than city practices. In Ireland, there is a direct financial incentive for general practices to acquire foetal monitors. The Maternity and Infant Care Scheme (MIS) provides an agreed programme of care to all expectant mothers (public and private patients) who are ordinarily resident in Ireland. In general, the scheme allows for seven GP visits during pregnancy and two post-natal GP visits for public and private patients [8]. Interestingly, practices in the HSE West are more likely to have ECG machines and 24hr blood pressure monitors. A typical general practice in the HSE West region is smaller and more likely to be remote relative to secondary care services than their counterparts in the rest of the country [24]. While this finding is in contrast to the epidemic hypothesis that information acquisition positively influences adoption, it may be capturing 'compensation' effects whereby these practices with less access to secondary health care services need to provide a greater portfolio of services to their patients [22, 34, 35].

Training practices and practices that hold clinics are likely to adopt medical equipment. Training practices are more likely to adopt ECG machines and spirometers; practices which hold clinics are more likely to adopt ECG machines and minor surgery equipment. Both these findings indicate evidence of epidemic learning effects. A UK study also reported that training practices were more likely to use medical equipment than their non-training counterparts [23].

The remaining epidemic effect variables show limited influence on adoption decision-making. Increasing CME attendance positive influences adoption of 24hr blood pressure monitors. Surprisingly, frequency of visits from suppliers of medical equipment only influences the use of one item of medical equipment, cryotherapy equipment, and this is at the 10% level of significance. The professional and academic involvement variable positively influences the adoption of two items of medical equipment, but only at the 10% level of significance.

4.3: Learning-by-Using Effects on Medical Equipment Adoption

The 'cumulative length of use' variables, which capture learning-by-using effects, are consistently signed and significant across all six items of medical equipment. Therefore practices with the greatest experience of using medical equipment are more likely to adopt a new item of medical equipment. This indicates that practices learn from using a portfolio of medical equipment over time, and this experiential learning positively influences their adoption decision-making. Although there is a limited body of empirical work examining the influence of learning-by-using effects on the uptake of new medical technologies, Bourke and Roper [16] find similarly strong evidence of learning-by-using effects which positively influence prescribing innovation.

5: Conclusion

This study's contribution is twofold. It is the first to examine the adoption of multiple medical technologies by GP practices. It is also the first to examine such decision-making through the lens of commercial, informational and experiential stimuli. Our results provide evidence of some commonalties in the determinants of medical equipment use in Irish general practices. Most notably, our empirical results reveal that learning-by-using effects consistently influence the use of all six items of medical equipment; practices with more experience of medical equipment are more likely to adopt another medical technology. This finding is strongly statistically significant and consistent across all six items of medical equipment examined. This finding is consistent with the positive relationship also reported between learning-by-using effects and adoption of new drugs by GPs [16]. In relation to practice characteristics, we find that practice size and nursing support positively influence medical equipment use. While we find some evidence of epidemic learning effects, there is little consistency across the six items of medical equipment in relation to specific variables.

Our results emphasise the importance of 'applied' learning or learning-by-doing in a rather different context to that in which it is usually discussed in the health literature [38]. Specifically, it is widely accepted that in clinical practice the resolution or reduction of uncertainty occurs through 'applied' learning, trial, error, and seeming serendipity [2]. In the medical innovation literature, there has also been considerable focus on how knowledge generated from a trial-and-error process results in medical devices and technologies, with or without modifications, being used in new applications. Examples include: the laparoscope, commonly used in gynaecological procedures, modified by attaching a camera for use in orthopaedic procedures; and *buproprion*, introduced as an antidepressant drug, subsequently used as an aid in smoking cessation programmes [2]. However, our findings indicate that the knowledge generated by learning-by-using experiences in health care settings, not only influences medical innovations of this magnitude, but also influences the adoption and use of health care innovations by health care practitioners. To date, there has been little empirical testing of how learning-by-using or 'applied' learning within health care can have commercial and organisational, as well as clinical, benefits in small health care organisations, such as GP practices.

We also find that practice size, in terms of number of GPs and number of patients, positively influences medical equipment adoption. This indicates that the returns from adoption are greater for larger practices; these practices have a greater ability to bear the financial costs of investing in new equipment (purchase of some of the items of equipment would involve a considerable financial outlay) and also the benefits from adoption are distributed more widely across GPs and patients. We also find nursing support positively influences medical equipment adoption.[11] Within the Irish general practice setting, the influence of nursing support on investments in medical equipment is most likely to be indirect in nature. However, this finding is particularly interestingly as a previous study reported the positive influence of nursing support on prescribing innovation by Irish GPs [16]. In addition, evidence of firm size and human capital influencing technology adoption is often reported in the innovation literature [10, 39].

[11] It is important to note that practices with nursing support should not be considered a proxy for practice size, as this variable is weakly correlated with the number of GPs' and number of patients' variables.

It is important to note that in the Irish context investments in medical equipment are borne by the practice, and while this may explain why some practices are more poorly equipped than others, our findings suggest that their limited experience with medical equipment negatively affects their subsequent investment decisions. If policymakers want to influence investment in medical equipment to ensure consistent service provision, they need to consider targeting poorly equipped practices who are the least likely to invest in new equipment. In other health care systems, such as the UK's NHS, 'hub and spoke' service delivery models are being implemented in many areas. In general, a 'hub' would be a larger better- equipped centre of excellence, with a number of 'spokes', i.e. smaller centres, in the same geographical area. Such a model in a primary care setting enables the provision of a wider range of services across a geographical area without the need for individual practices to make considerable investments in medical equipment. However, at present, no such 'hub and spoke' model of primary care delivery operates in Ireland. Our findings indicate the potential for 'spoke' practices to learn and benefit from the wider range of equipment available in 'hub' practices.

A key finding from this work is learning is important in adoption decision-making in a health care setting. General practices which adopt and use medical equipment learn from that experience and so are more likely to adopt other items of medical equipment. A potential message, therefore, is that subsidising one type of medical equipment may lead to the catalytic up-take of other equipment. Our study also highlights some barriers to medical equipment adoption. In particular, smaller practices, in terms of GPs and patients, are less likely to adopt medical equipment. Similarly, practices operating without the assistance of nursing support, are less likely to have a broad portfolio of medical equipment. This indicates the need for a differentiated policy approach to broaden adoption. In other work using this dataset, we examine the adoption of Information and Communication Technology (ICT) by general practices. We find that practices in the HSE South are more intensive users of ICT. This finding illustrates the effectiveness of an initiative introduced by the Southern Health Board to accelerate the adoption process. The HSE South implemented a strategy centred on information-sharing and education in relation to ICT use in general practices. We would expect similar targeted initiatives in relation to practice equipment to also prove successful.

Our study is limited in three important respects. First, it is based on cross-sectional data rather than the observed behaviour of GP practices over a period of time. This limits the complexity of our analytical approach, particularly as we have no historical information on the changing characteristics of the practices themselves. Second, the survey-based nature of the study – although covering around a third of Irish GP practices – raises potential issues of selection and response bias. Overcoming such issues entirely would require the use of real time administrative (or purchasing) data on practices' adoption history, data which is not available for Ireland. Finally, it is important to acknowledge that, reflecting much of the adoption literature, we focus here on the role of GP and practice characteristics on adoption. We pay less attention to health policy or pricing impacts on adoption, both of which are potentially interesting areas for future research.

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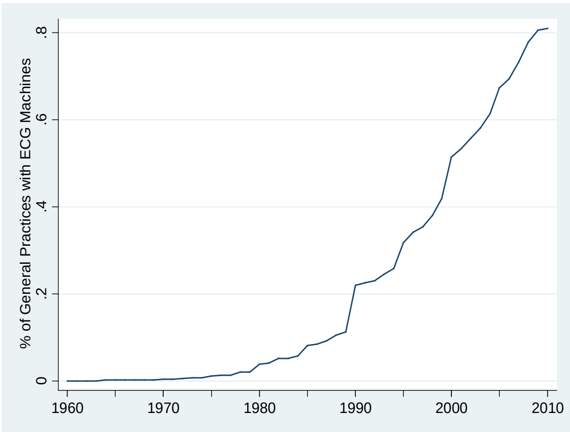
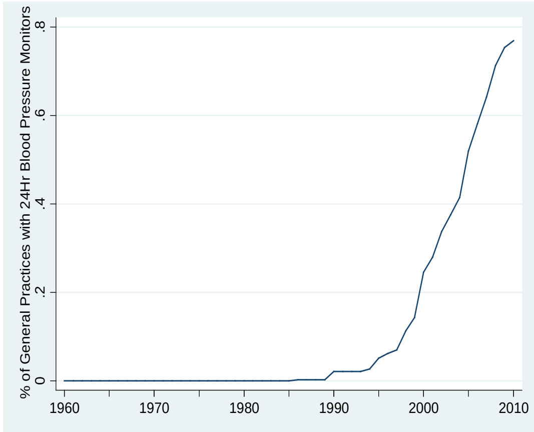
Figure 1: Proportion of General Practices Adopting Medical Equipment

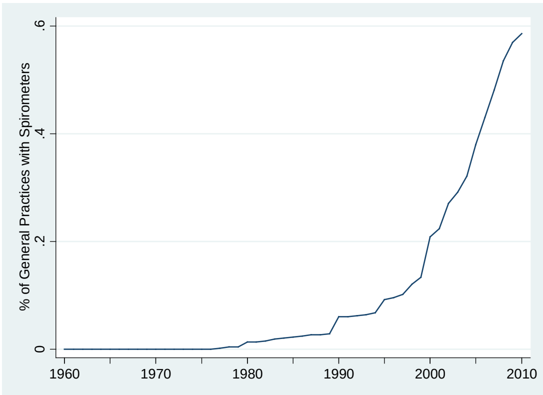
A: ECG Machines



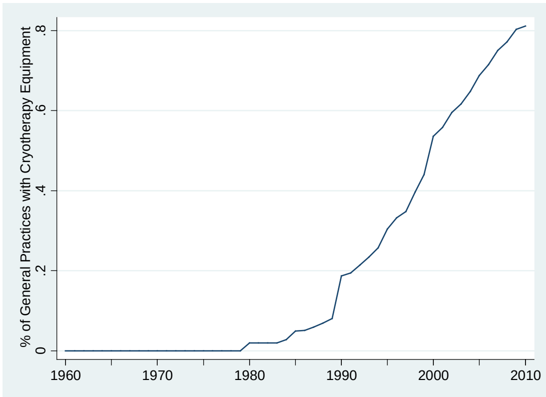
B: 24 Hr Blood Pressure Monitors



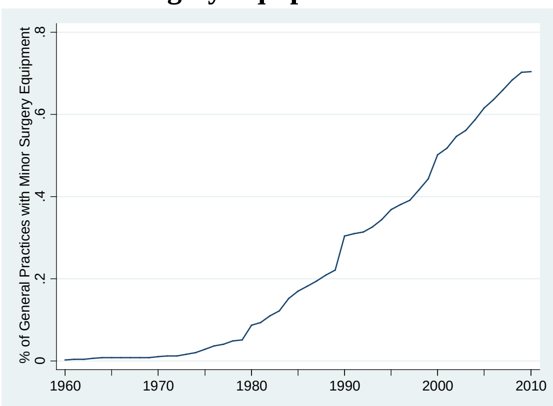
C: Spirometers



D: Cryotherapy Equipment



E: Minor Surgery Equipment



F: Foetal Monitors

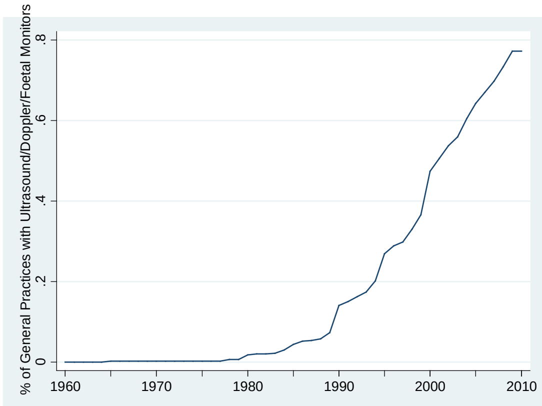


Table 1: Survey Questionnaire: Sample Frame, Response Rates and Representativeness

1(a): Stages of Sample Frame Construction

	Number of Units
Target population elements identified for sample frame[1]	2,363
Duplicates of target population elements in sample frame[2]	862
Target Population Sample Frame	**1501**
Ineligible units – questionnaires returned unanswered	84
Final Sample Frame	**1417**

Note 1: The Golden Pages website provided the sample frame for this study. **Note 2:** As our focus is on the general practice rather than the GP, it was necessary to identify one GP per practice to be included in the sample frame. Where there was more than one GP listed at the same address, all GPs were removed except one. Also if there were two addresses for the one GP (two practice addresses or a home and practice address), one of the addresses was removed from the sample frame.

1(b): Response Rates by HSE Region

	Distributed Questionnaires	**Returned Questionnaires**	**Response Rate**
Dublin Mid-Leinster	385	141	37%
Dublin North-East	235	91	39%
South	412	211	51%
West	385	157	41%
Total	**1417**	**601**	**42%**

Note 1: The Health Service Executive (HSE) is responsible for delivering health care for the population of Ireland. There are four administrative regions in the HSE. **Note 2:** 600 questionnaires were returned with HSE identifiers. One questionnaire was returned without a HSE identifier.

1(c): Sample Representativeness: Chi-Square Goodness-of-Fit Test

	Full Sample (600)		**Adjusted Sample** (589)	
HSE Region	Observed	Expected	Observed	Expected
Dublin North-East	91	102 (17%)	91	100(17%)
Dublin Mid-Leinster	141	162 (27%)	141	159(27%)
West	157	162(27%)	157	159(27%)
South	211	174(29%)	200	170(29%)
Total	600	600(100%)	588	589(100%)
	Chi-Square = 11.931, p<0.05		Chi-Square = 7.566, p>0.05	

Table 2: Descriptive Statistics of Explanatory Variables

Variable Name	N	Mean	St. Dev.
Rank Effects			
Number of GPs	596	2.701	1.667
Log of Patients	559	8.072	0.749
Public Patients/ Total Patients	559	0.375	0.201
Nursing Support (d)	597	0.807	0.395
Administrative Support (d)	601	0.914	0.281
Age >40 (d)	601	0.250	0.433
Male Dominated (d)	601	0.509	0.500
Learning By Using Effects			
Log of Cumulative Length of Use (ex. ECG)	435	3.463	1.005
Log of Cumulative Length of Use (ex. BPM)	441	3.547	1.036
Log of Cumulative Length of Use (ex. Spiro)	440	3.609	0.967
Log of Cumulative Length of Use (ex. Cyro)	441	3.466	0.988
Log of Cumulative Length of Use (ex. Minor)	460	3.444	0.955
Log of Cumulative Length of Use (ex. Foetal)	456	3.432	1.071
Epidemic Effects			
Rural	601	0.185	0.388
Town	601	0.501	0.500
City	601	0.315	0.465
HSE West (d)	600	0.262	0.440
Training Practice (d)	595	0.291	0.455
Clinic (d)	601	0.494	0.500
Supplier Visits = 0	589	0.408	0.492
Supplier Visits = 1.5	589	0.366	0.482
Supplier Visits = 4	589	0.157	0.364
Supplier Visits = 7	589	0.039	0.194
Supplier Visits = 10	589	0.031	0.172
Professional & Academic Activity (d)	601	0.696	0.461
CME Meetings = 0	601	0.085	0.279
CME Meetings = 1.5	601	0.072	0.258
CME Meetings = 4	601	0.305	0.461
CME Meetings =7	601	0.539	0.499

Note: Log of patients is used as the original ‘number of patients’ variable is positively skewed. The cumulative length of use variables are also logged due to a positively skewed distribution and to ease interpretation.The Supplier Visits variable consists of 5 numeric categories, which represent midpoints of ordered categories: 0, 1.5, 4, 7 and 10. The CME Meetings variable consists of 4 numeric categories which represent midpoints of ordered categories: 0, 1.5, 4 and 7. Professional and Academic Activity takes a value of one if the GP is involved in one or more of the following: committee member of professional organisation, affiliated with an academic institution, involved in research projects, and completed/completing an ICGP course. N differs due to item non-response.

Table 3: Variance Covariance Matrix

	ECG	24Hr BPM	Spirometer	Cryotherapy	Minor Surgery	Foetal Monitor
ECG	1	0.24*	-0.01	-0.09	0.27	-1.46*
24 Hr BPM	0.24*	1	0.40***	-0.25*	-0.33***	-0.04
Spirometer	0.01	0.40***	1	-0.25**	-0.09	0.05
Cryotherapy	-0.09	-0.25*	-0.25**	1	0.08	-0.01
Minor Surgery	0.27	-0.33***	-0.09	0.08	1	0.01
Foetal Monitor	-1.46	-0.04	0.05	-0.01	-0.01	1

Table 4: Multivariate Probit of Medical Equipment Use

	ECG	24 Hr BPM	Spiro-meter	Cryo-therapy	Minor Surgery	Foetal Monitor
Equilibrium Effects – Rank Effects						
Number of GPs	-0.058	0.276**	0.084	0.155*	0.028	0.205***
	(-0.108)	(-0.114)	(-0.08)	(-0.089)	(-0.069)	(-0.078)
Log of Patients	0.379**	-0.202	0.298**			0.244
	(-0.193)	(-0.169)	(-0.147)			(-0.171)
Proportion of Public Patients	0.637	0.365		-0.084	-1.001**	0.391
	(-0.534)	(-0.467)		(-0.431)	(-0.402)	(-0.438)
Nursing Support	0.434*	0.930***	0.357*	-0.307	0.387*	
	(-0.248)	(-0.232)	(-0.21)	(-0.251)	(-0.219)	
Administrative Support			-0.612*			0.635**
			(-0.324)			(-0.311)
All GPs > 40		-0.334	-0.044	-0.323	-0.325	0.593***
		(-0.238)	(-0.208)	(-0.235)	(-0.214)	(-0.226)
Male Dominated	0.283	0.021	0.250*	-0.276	0.342**	-0.071
	(-0.197)	(-0.182)	(-0.15)	(-0.182)	(-0.161)	(-0.169)
Learning-By-Using Effects						
Portfolio	0.409***	0.401***	0.451***	0.563***	0.485***	0.226**
	(-0.102)	(-0.098)	(-0.101)	(-0.1)	(-0.095)	(-0.091)
Disequilibrium Effects – Epidemic Effects						
Town	0.2	-0.247	-0.087			0.496***
	(-0.196)	(-0.208)	(-0.146)			(-0.188)
Rural		-0.426		0.25	0.226	0.357
		(-0.262)		(-0.241)	(-0.22)	(-0.258)
HSE West	0.789***	0.505**	0.209	-0.09	0.114	0.186
	(-0.264)	(-0.209)	(-0.17)	(-0.202)	(-0.179)	(-0.193)
Training Practice	0.971***	-0.029	0.581***	0.145	0.008	0.306
	(-0.373)	(-0.247)	(-0.194)	(-0.248)	(-0.207)	(-0.226)
Clinic	0.565***	0.106	0.233	-0.135	0.275*	0.071
	(-0.203)	(-0.179)	(-0.149)	(-0.183)	(-0.16)	(-0.178)

Table 4 (continued): Multivariate Probit of Medical Equipment Use

	ECG	24 Hr BPM	Spiro-meter	Cryo-therapy	Minor Surgery	Foetal Monitor
Supplier Visits	0.145			0.139*	0.005	
	(-0.09)			(-0.08)	(-0.058)	
Professional & Academic Activity	0.148	0.308*	0.235	0.359*	0.197	-0.027
	(-0.205)	(-0.185)	(-0.159)	(-0.187)	(-0.169)	(-0.184)
CME Meetings	-0.025	0.072**	-0.018			-0.008
	(-0.042)	(-0.034)	(-0.03)			(-0.035)
	Chi- Square = 394.902			P value = 0.000		n = 396

Notes: Portfolio variables differs with respect to each adoption decision (See Table 1). Coefficients are reported with standard errors in parentheses. *** denotes significance at the 1 per cent level; ** at the 5 per cent level and * at the 10 per cent level. Variable definitions are given in Table 1. Initially, six Probit models were estimated including all explanatory variables. Subsequently, in a general to simple modelling approach, variables with z-statistics of less than |0.5| were excluded from the models. We tested the robustness of the preferred models by ensuring that the significant variables did not differ in terms of sign or significance from the initial models. The explanatory variables from the preferred Probit models are included in the multivariate Probit model.