

Research Paper ■

Predicting the Adoption of Electronic Health Records by Physicians: When Will Health Care be Paperless?

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Abstract Objectives: The purpose of this study was threefold. First, we gathered and synthesized the historic literature regarding electronic health record (EHR) adoption rates among physicians in small practices (ten or fewer members). Next, we constructed models to project estimated future EHR adoption trends and timelines. We then determined the likelihood of achieving universal EHR adoption in the near future and articulate how barriers can be overcome in the small and solo practice medical environment.

Design: This study used EHR adoption data from six previous surveys of small practices to estimate historic market penetration rates. Applying technology diffusion theory, three future adoption scenarios, optimistic, best estimate, and conservative, are empirically derived.

Measurement: EHR adoption parameters, external and internal coefficients of influence, are estimated using Bass diffusion models.

Results: All three EHR scenarios display the characteristic diffusion S curve that is indicative that the technology is likely to achieve significant market penetration, given enough time. Under current conditions, EHR adoption will reach its maximum market share in 2024 in the small practice setting.

Conclusion: The promise of improved care quality and cost control has prompted a call for universal EHR adoption by 2014. The EHR products now available are unlikely to achieve full diffusion in a critical market segment within the time frame being targeted by policy makers.

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On April 27, 2004, President Bush¹ issued an executive order establishing the Office of the National Coordinator for Health Information Technology (ONCHIT) with the mission of implementing electronic health records (EHRs), nationwide, within ten years. Shortly thereafter, David Brailer was appointed the National Coordinator of this effort and introduced a strategic framework for fulfilling the universal adoption mandate.² Significant barriers exist to achieving this lofty but worthy goal,³ and many of these are acknowledged in Brailer's framework. Given that this is not the first national call for achieving a paperless health care system, much can be learned from our nation's experience.

In 1991, the Institute of Medicine (IOM) issued a report⁴ that also called for paperless health records within ten years. As important and visionary as this call was, it received far less media, scholarly, and governmental attention compared to more recent reports by the IOM.^{5,6} To date, progress in integrating EHRs into the health care workplace has been

slow,^{7,8} and the ambulatory setting has lagged other areas.⁹ The universal adoption of EHRs will bring with it many benefits including improvements in quality and the concomitant reduction in medical error rates, enhanced cost-effectiveness, and greater consumer involvement in their health care decision making.¹⁰ However, recent data suggest that less than 18% of physicians use EHRs in their offices.¹¹ Therefore, the question remains: Will the U.S. health system achieve universal EHR adoption by 2014? And if not, what is the likely time horizon?

The purpose of this study was to answer the preceding questions by constructing three models that project likely EHR adoption patterns based on historic estimates. As such, this study has two aims. First, we quantified and graphically depicted the historic trend of EHR adoption among U.S. physicians in small practices (ten or fewer members) by applying diffusion modeling techniques¹² to EHR adoption estimates from six previous studies.^{7,11,13–16} Based on that information, future implementation trends were extrapolated and discussed in terms of the two factors that drive the diffusion process—external and internal social influences.¹⁷ Second, based on published studies and the derived models, we determined the most probable time horizon for achieving ubiquitous EHR adoption.

The current study makes three new contributions to the EHR research literature and policy debate. First, it allows policy makers to better understand how external and internal influences in the small practice setting will affect EHR adoption among physicians. Second, it provides a benchmarking model that can be used for planning and evaluating EHR

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adoption incentive programs that target small practices. Because small medical practices, are expected to be the last setting to widely adopt EHR technology,⁹ they in effect become the leading indicator for achieving a universally paperless health system by 2014. The current study also provides a means for systematically quantifying and tracking that indicator. Finally, the present study empirically estimates three future adoption scenarios using the Technology Diffusion Model.

Methods

The Technology Diffusion Model (TDM)

Rogers¹⁷ is credited with creating the technology diffusion theory that describes innovators (i.e., first adopters), early adopters, early majority, late majority, and laggards' adoption pattern. Further research by Bass¹² empirically modeled the factors that predict new technologies' diffusion patterns as a function of *external* and *internal influences*. External influences, commonly labeled in the diffusion literature as *innovation factors*, are driven by information from a source outside the potential adopter's social system. Internal influences on a provider's decision to adopt a new technology, within their social system and are often referred to as *social contagions* in the diffusion literature.¹⁸

Bass¹² was the first to develop commercial applications of such diffusion models. His models were developed to predict the uptake of consumer products based on the influence of various types of advertising campaigns. The Bass model predicts how many customers will eventually adopt a new product, and when they will do so, based on early market penetration rates. The basic formula for calculating the percentage of adopters at any point, using discrete time notation, can be written as¹⁹:

$$F(t) = \left(1 - e^{-(p+q)t}\right) / \left(1 + \left(\frac{q}{p}\right)e^{-(p+q)t}\right), \quad (\text{Eq. 1})$$

where $F(t)$ = the number of adoptions occurring in period t , p = coefficient of innovation capturing the intrinsic tendency to adopt and the effect of time invariant external influences, q = coefficient of imitation or social contagion capturing the extent to which the probability that one adopts (given that one has not yet done so) increases with the proportion of eventual adopters who have already opted in, and t = period of measurement.

The model has several attractive properties. For example, given multiple time point measurements, it is possible to solve for p and q . The parameters p and q provide information about the rate of diffusion. A high value for p indicates that the diffusion has a quick start but also tapers off quickly. A high value of q indicates that the diffusion starts slowly but later accelerates. When q is larger than p , the cumulative number of adopters $F(t) + F(t - 1)$ follows the type of S curve often observed for high risk, innovative products that take extended time frames to become widely used. When q is smaller than p , the cumulative number of adopters follows an inverse J curve often observed for less risky innovations, such as the adoption of new consumer durables (e.g., washers and dryers). Once p and q are known, the time (t^*) at which the peak adoption rate occurs (i.e., the

period when the largest number of individuals adopts) can be calculated as²⁰:

$$t^* = \ln(q/p)/(p + q) \quad (\text{Eq. 2})$$

This calculation is commonly referred to as the inflection or "tipping point"¹⁸ when the diffusion paradigm becomes self-sustaining.

To forecast the adoption path of a new product with a diffusion model, the researcher assigns values for the model's parameters based on experiences with comparable goods. From a marketing perspective, this is problematic because realistic forecasts for new product adoption are needed early on in the product's life, when very few data exist. However, once sufficient adoption level data become available, usually after three or more periods, the researcher can then estimate p and q using the basic Bass model (Eq. 1). In the case of EHRs, empirically derived point estimates of medical practices' adoption levels are relatively rare. However, an adequate number of studies have now been conducted to estimate the equation. These studies are described in the next section.

Data Sources

Data for the current analyses were drawn from six previous studies (please see Table 1, "Studies of EHR Adoption in the Ambulatory Setting," available as a *JAMIA* online supplement at www.jamia.org). Heuristic estimates, or "best guesses," of physicians' current EHR adoption levels in their practice setting vary widely and range from 5% to 25%.^{21,22} Using published data, point estimates for EHR adoption rates were obtained. For example, empirical studies of EHR adoption conducted in both 2001²³ and 2002¹⁴ served as those periods' estimates. Additionally, there were four separate studies conducted during 2003.^{7,11,13,16} The Audet et al.⁷ study is the most extensive to date and found that between 18% and 24% of physicians' in small practices used EHRs routinely in their offices during 2003. The other three studies' estimates also fell within that range. Therefore, the four studies' estimates of office-based EHR use, in practices with fewer than ten practitioners, were averaged and gave a point estimate of 18.325% (standard deviation [SD] = 1.828). Given these three point estimates, it is possible to empirically derive the diffusion curves' historical shape, potential future trends, and the external (p) and internal (q) influence coefficients.

Diffusion Estimation Technique

The statistical extrapolation was conducted in Microsoft Excel using the linear optimization tool. The object was to have unique estimates for the external and internal influence coefficients that approximated the known adopter percentages as closely as possible for all three years. The objective function was the summed differences between estimated and actual adoption levels for the three known years, and the target value was zero, or as close to zero as possible. One constraint was applied to the optimization routine. The difference between the actual and estimated percentages of adopters for any year had to be less than 0.5% in absolute terms.

All the studies analyzed provided either current adoption level ranges or enough information to calculate the SD of estimates for that year. In the case of 2003, the year with four separate analyses, the SD of the individual estimates was calculated (SD = 1.828). The 2001 and 2002 studies' SDs were 0.75 and 1.75, respectively. The SDs were both added and

Table 2 ■ Diffusion Coefficient Estimates, Tipping Points, and 2014 Adoption Rates

Scenarios	External Diffusion Coefficient (p)	Internal Diffusion Coefficient (q)	Tipping Point	2014 Adoption Percentage
Optimistic	.0047	.2001	2009	71.61%
Best Estimate	.0054	.1673	2011	61.93%
Conservative	.0053	.1544	2012	56.20%

subtracted from the best estimate to create two additional scenarios, the “optimistic” and “conservative” diffusion curve estimates, using the linear optimization approach described above.

Results

Statistical Estimates of EHR Diffusion Curves

Using Eq. 1 and linear optimization, the coefficients of external (p) and internal (q) influences were estimated for all three scenarios. Table 2 presents the three different diffusion scenarios’ external and internal influence coefficients, their tipping points (Eq. 2), and the projected adoption levels in 2014, the ONCHIT’s²⁴ goal for universal EHR use. All three scenarios display the characteristic S curve that is indicative that the technology is likely to achieve significant market penetration, given enough time.

Figure 1 presents the EHR diffusion curves based on the standard Bass Model of Innovation Diffusion and the estimates of physicians’ EHR adoption rates outlined in Table 2. Based on the 2001–2003 data, EHR prevalence in the small practice

setting for 1991 was less than 1%. This finding is consistent with the initial IOM report’s findings for that period and provides external validity to this study’s analyses. The extrapolated model indicates that EHR diffusion will plateau for all three models around 2024 with 95%, 90%, and 87% adoption levels, respectively. The implications of these three models for policy makers are discussed next.

Discussion

Implications for Achieving the 2014 EHR Diffusion Goal

Two questions motivated this study. First, can the U.S. health care system achieve universal EHR adoption by 2014? Based on recent assessments of small practices’ EHR adoption rates and prospective innovation diffusion modeling, we present evidence to suggest the answer is no. The question then becomes what is the magnitude of the challenge facing policy makers, or what is the most likely time horizon for universal EHR adoption? The most conservative estimate is that 86.6% of physicians in small practices will be using EHRs in 2024. In other words, at the current adoption rate, the goal of universal adoption will take more than twice as long as desired. This gives rise to a third question: Where should policy makers focus their efforts to accelerate EHR adoption?

Identifying the Providers to Target for EHR Adoption
 Nearly 60% of all physicians practice in groups with ten or fewer doctors, and a significant number of all patient encounters therefore occur in these settings.^{25,26} Thus, small ambulatory practices are where the patient histories essential to an effective nationwide EHR system are generated. Further, physicians in small practices are likely to be among the late

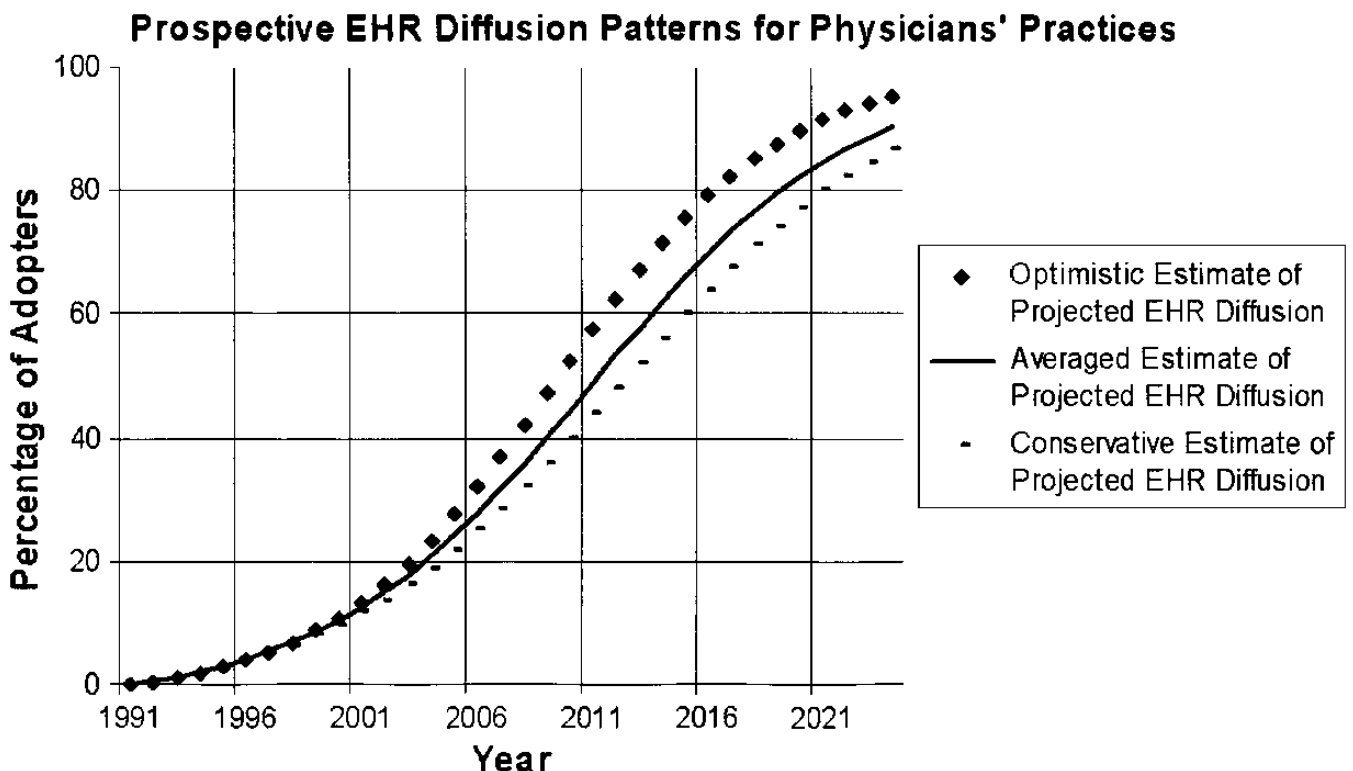


Figure 1. Three models of electronic health record (EHR) diffusion based on prior empirical estimates.

majority and laggards in the product adoption life cycle. Therefore, the critical path for effectively achieving the EHR capabilities sought in the 2014 universal adoption goal runs through small group and solo practices. The potential to accelerate the EHR adoption rate by increasing the external (p) and internal (q) influence coefficients among these providers is considered next.

External Factors Influencing EHR Adoption

The external diffusion coefficient estimates for EHRs are already relatively large compared to other medical equipment technologies, such as ultrasound imaging ($p = 0.000$), mammography ($p = 0.000$), and use of computed tomography scanners ($p = 0.036$), all of which diffused quickly.^{27,28} Compared to other consumer electronics designed to support decision making, such as calculators ($p = 0.143$) and personal computers ($p = 0.121$), the external influence coefficient is relatively small. However, reaching the tipping point in EHR adoption is qualitatively different from electronic tools such as calculators and computers.

Electronic health record implementations represent a disruptive change in the health care workplace. In addition to the introduction of new equipment, the job design of interconnected health professionals must be reengineered to effectively and efficiently accommodate the technology. In this respect, EHRs may follow the slower adoption pattern of "general purpose" technologies that are pervasive today, such as electric motors in manufacturing, which required the transformation of entire industries. General purpose technologies typically take relatively long periods to reach the diffusion tipping point and do not deliver productivity gains immediately upon arrival.²⁹ The latter point has been a frequently identified barrier to EHR adoption.⁹ Nevertheless, other countries have been able to effectively promote EHR diffusion.

In other mature health care systems, such as Australia and Western Europe, various forms of EHRs have been widely adopted.³⁰ In those systems, there have been significant governmental efforts to partner with physicians or subsidize the cost of the new technology, respectively. The policy mechanism most commonly discussed for increasing EHR's external influence coefficient in the United States is the introduction of clinical reporting mandates. The Centers for Medicare and Medicaid Services (CMS) has introduced several new reporting requirements for hospitals with quality improvement and cost control as the primary objectives.³¹ As reporting requirements increase, the only feasible mechanism for gathering such data will be the EHR. While such programs may be of some use, they may not advance the goal of *full* EHR adoption significantly, because U.S. providers tend to respond negatively to such mandated-use policies,^{32,33} particularly in comparison to their international counterparts.³⁴ Therefore, some external stakeholders are taking a more positive approach to accelerating EHR adoption rates.

Pay-for-performance (P4P) programs would reward physicians for using EHRs in their clinical practices. There are currently over 100 P4P programs in the United States designed to improve the quality of care and adherence to best demonstrated practices, often relying on EHRs to provide the required documentation.³⁵ CMS, under its demonstration authority, intends to carry out P4P demonstration programs

in the future related to EHRs. Cisco, a computer networking company, introduced a program that paid California physicians' groups more than \$50 million for achieving key quality metrics and investing in EHR technology in 2004.³⁶ Despite these positive incentives, some physicians see P4P programs as a third-party attempt to overly influence medical practice, decrease costs, and increase profits for payers.³⁵

As such, relying solely on external influences to achieve full EHR diffusion by 2014 is unlikely to be a successful strategy. The internal influence factor appears to be more powerful for accelerating diffusion than the external one. This phenomenon is apparent by comparing the optimistic scenario's external and internal coefficients (Table 2) to the other two scenarios' values. The external influence factor in the optimistic model is slightly *lower* than the other two models' values while the internal coefficient is markedly higher. This suggests that increasing the internal influences (e.g., social contagions) has a far greater impact on the overall adoption rate than a similar increase in external factors. Furthermore, it is possible for external stakeholders to have a positive impact on social networks' internal technology diffusion mechanisms, as noted below.

Internal Factors Affecting EHR Adoption

Compared to other medical technologies that diffused rapidly, such as ultrasound imaging ($q = 0.510$) and mammography ($q = 0.738$), the internal influence coefficients for all the EHR models are relatively low. In order to rapidly accelerate a technology's diffusion, it is essential to increase the internal or social contagion factors that influence adoption decisions. Otherwise, EHR adoption rates among small practices will remain relatively low and time horizons for complete adoption will remain distant.

One aspect of adopting EHRs that physicians in small practices have had to internalize is the system's initial purchase and ongoing operational costs. The return on investment for an EHR system does not accrue to the provider in the short run under many reimbursement schemes.³⁷ Instead, the savings from improved care efficiency and quality typically flow back to health care insurers or payers as a reduction in service use.³⁸ Another significant barrier to adoption has been vendor transience; many early EHR companies are no longer in business or are in precarious financial positions.³⁹

The adoption risk associated with vendor volatility could be mitigated if a common data standard were implemented across the sector. There would still be significant changeover costs in the event of a vendor failure, but the initial cost of creating the EHRs would not be totally lost. In addition to the monetary costs, system changeovers negatively affect physicians' workflows, something they are keen to avoid.⁴⁰

Physicians have historically relied on their professional peers as their primary source of information related to new technologies.^{41,42} The medical community's professional culture makes it a very close-knit social network that views external attempts at instituting controls as an assault on its autonomy.⁴³ Further, the physician community does not, in general, have a strong grasp of the quality improvement processes that are being targeted at them.⁴⁴ Collectively, the medical community's social mechanisms that influence adoption decisions view EHRs as a potential threat to professional autonomy. This may be particularly true among physicians in

small practices who value the freedom and autonomy they provide.

There is extensive research on ways to influence physicians' internal social networks. Passive dissemination strategies, such as journal articles and mailings, are typically ineffective.⁴⁵ The use of "thought leaders" to influence social networks and change clinical behaviors has experienced some success. However, given that many of targeted adopters are working in solo practices, this may not be a broadly applicable intervention. Therefore, an interactive educational strategy is likely to be most influential in penetrating physicians' social networks, particularly those in small practices.

Educating Physicians' Social Networks

There are three interactive educational mechanisms that external stakeholders might use to increase the internal influence coefficient related to EHR use. The first is medical education. Many medical schools and residency programs do not currently employ or train future physicians in the use of EHRs. Training the future medical workforce to rely on EHRs and their decision-support tools can only serve to accelerate universal EHR adoption. Further, the acculturating of medical students and residents to EHRs during this formative period signals that EHRs are valued by the profession. The second potential channel for influencing physicians' social networks is through the continuing medical education (CME) requirement. However, CME interventions have not proven to be particularly effective in changing providers' behaviors in other clinical areas.^{46,47} The last active educational mechanism for accessing physicians' social networks is academic detailing. Academic detailing involves in-depth one-on-one training sessions with physicians and is an effective mechanism for altering physicians' behaviors.⁴⁸⁻⁵⁰

Collectively, the interactive educational approaches hold the greatest power to hasten universal EHR adoption. However, they also carry the highest price tag and require major coordination efforts to implement. It is essential that medical education, including residencies, takes place in environments that use EHRs. In addition, programs designed to give physicians extensive academic detailing in their practices provide the greatest promise for spurring universal adoption by 2014.

Measuring the Level of EHR Diffusion

The present study's projections are limited in two respects. From a theoretical perspective, the future diffusion of EHRs may follow a discontinuous rather than an S-shaped trajectory. Under such conditions, the EHR adoption rate will not grow in a gradual, evolutionary process, but rather a series of revolutionary leaps forward will occur as external pressures and new product innovations increase.⁵¹ Given the significant amount of activity in the health care arena related to increasing EHR adoption, this scenario is one that may occur.

A second limitation in the study's design is that it relies on previously conducted survey estimates regarding historic EHR adoption rates. Consistent with all survey methodologies, the results of those studies may have been biased in an upward direction. This may have occurred because physicians who already used EHRs, "early adopters," were potentially more likely to respond to inquiries about such systems compared to nonusers. Also, respondents to the previous surveys may have provided answers to questions in a socially

desirable manner. In such instances, the inclination would be to respond positively on familiarity and frequency of EHR use. A third potential source of bias lies in how EHRs were defined in previous studies. Respondents may have viewed their nonclinical automated systems (i.e., electronic scheduling and billing) as EHRs. Moreover, users of less robust systems may have responded positively despite the fact that key capabilities of a minimal EHR may not have been present.⁵² All these biases serve to inflate the previous estimates of EHR adoption. Therefore, even our conservative estimates of future adoption trends may be overstated, creating a need for more rigorous studies.

Both limitations can be addressed by conducting more comprehensive surveys of small practices' EHR use. In particular, tracking the incidence of EHR adoption over time, using accepted statistical approaches and national sampling methodologies, would be helpful. The Agency for Healthcare Research and Quality has established the National Resource Center for Health Information Technology to monitor and disseminate information about EHR diffusion.⁵³ Therefore, it seems likely that improved assessments of adoption rates will be forthcoming.

Conclusion

Electronic health records hold promise in improving health care quality and efficiency. However, health care is decades behind other industries with respect to information technology (IT) adoption. Stakeholders in the medical community, including the government and other payers, have emphasized the urgent need to adopt IT systems. In the U.S. health care system, health IT and EHR use will likely continue to increase, but at what rate? This study suggests that the EHR products currently available are unlikely to achieve full diffusion in the desired time frames. Regardless of the products available, the factors influencing adoption patterns (i.e., external and internal coefficients) are also unlikely to change absent significant incentives that have a positive impact on small practice physicians' social networks. A lot of time has already elapsed between the introduction of viable EHR technologies and today. Referred to as "long intergenerational periods," slow progress in product innovations negatively affect subsequent adoption rates as the market tends to repeat its diffusion history.⁵⁴

There is growing recognition that the EHR diffusion process is multifaceted in nature and that no single tactic will successfully address all the barriers to adoption in the physicians' small practice setting.⁵⁵ The programs offered by Brailer and the ONCHIT addresses many of these issues. However, there is not an empirical evaluation framework for tracking progress to aid them in their efforts. This study provides such a framework and benchmarks to evaluate new programs' progress in increasing EHR adoption.

Future research that draws on cross-national comparisons of government programs and their effect on diffusion factors could help shape policy makers' attempts to accelerate EHR adoption among small providers. In particular, it would be informative to have in-depth information on how physicians and other providers react to the government-introduced standards. In addition, studying how patients in other countries reacted to EHRs' introduction of and the potential threats to their privacy are important issues because one commonly

stated goal of federal leaders is to increase consumers' access to the medical histories.

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