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Deepen electronic health record diffusion beyond breadth: game changers and decision drivers

Xuan Wang
The University of Texas Rio Grande Valley

Jun Sun
The University of Texas Rio Grande Valley, jun.sun@utrgv.edu

Ying Wang
The University of Texas Rio Grande Valley

Yi Liu

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Abstract

Cloud computing, financial incentive and patient-centered care are the game changers that deepen EHR diffusion beyond breadth. Based on the innovation diffusion theory (IDT), technology-organization-environment (TOE) framework and alignment literature, this study examines how these changes shape business requirement, service value and society need that drive different phases of EHR diffusion in terms of planning, adoption, usage and upgrade. A longitudinal analysis with the USA National Ambulatory Medical Care Survey (NAMCS) reveals the impacts of different drivers on EHR diffusion. In addition to quantitative results, interview observations corroborate the relationships among game changers, decision drivers and EHR diffusion. The findings provide healthcare providers, system vendors and policy-makers the insights on the best practices of promoting EHR diffusion for long-term success.

Keywords: EHR diffusion in breadth and depth; cloud computing; financial incentive; patient-centered care; longitudinal analysis; business requirement; service value; society need.

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1. Introduction

Compared with the paper chart approach, electronic health record (EHR) represents a technological innovation that greatly facilitates the utilization and exchange of patient information (Skolnik, 2011). The eventual goal is to enhance healthcare services by improving qualities and reducing errors (Cebul et al., 2011; Donaldson et al., 2000). For instance, a doctor may directly send an e-prescription to a pharmacy, which expedites the process and avoids possible confusions. Clinics in outpatient settings are primarily responsible for the collection and maintenance of patient records (Habib, 2010). They share the information with other healthcare organizations such as hospitals, pharmacies and insurance, which are the stakeholders concerning EHR usage together with patients (Furukawa et al., 2014).

When clinics make decisions regarding whether to implement EHR or not, they must consider the needs of customers and other stakeholders, especially in patient-centered care (Bergeson & Dean, 2006). High cost, extra workload, change avoidance and security threat are the major barriers to EHR adoption (Fernando et al., 2012; Fleming et al., 2011; Yang & Lee, 2016; Serrano et al., 2018). To promote the diffusion, the governments of many countries make favorable policies and give financial incentives. For instance, the USA passed the Economic and Clinical Health Information Technology (HITECH) act in 2009 to offer maximum $44,000 to $65,000 for doctors who implement EHR through Medicare and Medicaid (Blumenthal, 2009, 2010). The goal is to make sure that most of the clinics in the USA achieve the "meaningful use" of EHR to meet data quality and interchangeability requirements (Blumenthal & Tavenner, 2010; Jha, 2010). With the incentive program, "the act increased rate of adoption of EHRs from 3.2% in 2008 to 14.2%

in 2015. By 2017, 86% of office-based physicians had adopted an EHR and 96% of non-federal acute care hospitals has implemented certified health IT" (HIPAA, 2017).

During the last decade, cloud computing has emerged as a technology greatly changing the landscape of organizational IT operations through the provision of various dynamic web-based services (Baun et al., 2011; Regalado, 2011; Sabi et al., 2018). In the healthcare industry, cloud-based EHR is more attractive to clinics than traditional client-server EHR due to lower cost, easier access (e.g. with smartphones) and more powerful capabilities (especially analytics) (Crocker, 2016; Kankanhalli et al., 2016). Allowing healthcare providers to rent IT services rather than hosting them, cloud computing significantly reduces the technical and financial burdens, along with other benefits such as system maintenance and data backup (Sultan, 2014). Though health industry is not among the earliest to embrace cloud computing, there has been an irreversible trend that clinics migrate from client-server to cloud-based EHR and the market will be worth $10 Billion by 2021 (Frost & Sullivan, 2017).

Based on innovation diffusion theory (IDT), technology-organization-environment (TOE) framework and alignment literature, this study conceptualizes that EHR diffusion is an iterative process comprising four phases (i.e., planning, adoption, usage and upgrade) under the influences of business requirement, service value and society need. It then identifies relevant variables from the USA National Ambulatory Medical Care Survey (NAMCS) and conducts a longitudinal analysis over the recent 10 years that cover the movement of patient-centered care, launch of incentive program, and emergence of cloud computing. A qualitative assessment based on interview observations provides further insights on clinics' decision-making on EHR implementation. The findings yield helpful hints on how to facilitate EHR diffusion in breadth as well as in depth. By encouraging clinics to adopt new systems, the launch of incentive program

may greatly promote the breadth of EHR diffusion, but the effect can easily die out once the program ends. To make the process more sustainable in the long run, it is important to deepen EHR diffusion by facilitating system upgrade to the latest technological breakthrough.

2. EHR Diffusion

In the healthcare industry, EHR is a major technological innovation implemented and used by clinics and other healthcare organizations (Nguyen et al., 2014). Developed by Everett M. Rogers to study the spread of emerging technologies (e.g., Internet), the innovation diffusion theory (IDT) provides the appropriate lens to examine EHR diffusion. IDT explains how a new idea, practice or object penetrate a population through mass media and interpersonal communication channels over time (Rogers, 1995). Based on perceived characteristics of an innovation including relative advantage, compatibility, complexity, trialability and observability, people make decisions at different stages including knowledge, attitude, adoption, implementation, and confirmation.

Based on the normal distribution, IDT depicts the cumulative diffusion rate as a S-curve comprising five segments at different innovativeness levels. Lavishing massive time, energy, and creativity on new ideas, innovators (venturesome, 2.5%) try out an innovation and serve as its champions. Early adopters (respectable, 13.5%) join in once they find the innovation beneficial, and their feedback from usage is persuasive for the next level of diffusion. Early majority (deliberate, 34%) represent the mainstream adopters who are looking for a better solution than the existing ones in daily routines. Taking up another large proportion, late majority (skeptical, 34%) are more risk-averse, and wait until the technology becomes mature and relevant standards/policies get clear. The last to endorse the innovation are laggards (traditional, 16%), who fear the new idea would challenge the existing paradigm unless they are reassured by others.

Distinct in their technological approaches, client-server EHR and cloud-based EHR can be regarded as two innovation paradigms. In the case of USA, the government initially pushed clinics to adopt client-server EHR with regulations, legislations, and incentives. The high EHR adoption rates of around 90% by American clinics and hospitals (HIPAA, 2017) suggest that the innovation diffusion process has reached the last segment of laggards in the United States. But does it mean that EHR diffusion will stop moving forward?

With more and more cloud solutions emerging, many clinics are considering cloud-based EHR in place of client-server EHR for cost and service considerations (Griebel et al., 2015). The switch is not required by the government but totally at the discretion of healthcare providers. Between the two types of EHR, therefore, their diffusions vary somewhat in communication channels and adoption natures: more mass-media and mandatory for client-server EHR but more inter-personal and voluntary for cloud-based EHR. From the perspective of institutional theory, they represent coercive and mimetic forces respectively in EHR diffusion (Sherer et al., 2016).

As shown in Fig1, this study identifies four phases of EHR diffusion: the ones connected with solid lines concerning initial adoption and the ones connected with dash lines about system upgrade. From the exposure to technology that leads to positive or negative attitude, EHR Planning covers the knowledge and attitude stages of innovation decision process in IDT. Equivalent to the adoption stage, EHR Adoption pertains to a clinic's decision to employ the technology. EHR Usage involves regular practices of using the technology in daily routines by a clinic, corresponding to the implementation stage. Finally, EHR Upgrade pertains to the switch from client-server to cloud-based EHR based on evaluation and comparison, what the confirmation stage is about.

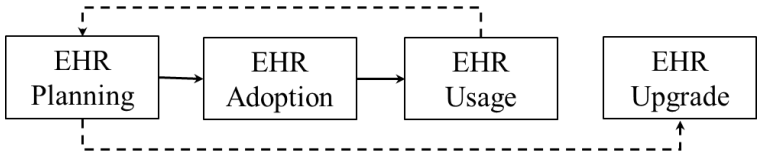

Fig1 EHR Diffusion Phases

For the initial adoption of EHR, most clinics mainly replaced the previous paper approach of maintaining patient records with the electronic approach as required. The implementation and operation of client-server EHR demand significant financial investment and in-house expertise to meet technical standards and comply with security and privacy requirements (Schweitzer, 2012). Based on user feedback and cloud computing, EHR vendors offer more up-to-date solutions to accommodate the economy, efficiency, utility and security/privacy concerns of relatively small clinics and other office-based providers (Gao & Sunyaev, 2019). If a vendor demonstrates a cloud-based solution that is compatible with but simpler and cheaper than the existing client-server system, a clinic is likely to make the plan for the switch (Sadoughi & Erfannia, 2019). For the decision of EHR upgrade, users can directly compare system characteristics along the dimensions of relative advantage, compatibility, complexity, trialability, and observability.

Clinics that migrate from client-server to cloud-based EHR enjoy better price plan, reduced operating cost, less IT infrastructure, smoother data exchange and improved quality of service (Schweitzer, 2012; Gao & Sunyaev, 2019; Sadoughi & Erfannia, 2019). Besides the typical sequence, it is possible that clinics (especially newly-opened) may go directly to cloud-based EHR. Yet they represent a small percentage as most clinics had already adopted client-server EHR before cloud-based solutions were widely available. Of course, EHR upgrade is not just limited to the switch from client-server to cloud-based systems but includes other major updates. In this sense, EHR diffusion is a continuous and iterative process in both breadth (adoption rate) and depth (system upgrade).

Most existing studies on EHR diffusion focus on client-server solutions, and the few concerning cloud-based solutions address why users make the decisions to adopt the new technology in various settings (Gao & Sunyaev, 2019; Schweitzer, 2012; Sadoughi & Erfannia, 2019). To have a more holistic understanding, this study examines system upgrade together with initial adoption. Initial adoption refers to the first-time adoption of an EHR system by a clinic that has used paper charts before. Meanwhile, system upgrade refers to switch to a new EHR system by a clinic that has already used an existing one for a certain period of time. Through the connection of usage and planning phases (which are largely missing in previous EHR adoption/diffusion studies), initial adoption and system upgrade integrate into an iterative process, in contrast to the original waterfall model of innovation diffusion. Cloud-computing, financial incentive and patient-centered care ushered in such a paradigmatic shift, and these game changers pertain to technology, organization and environment involved in EHR diffusion, respectively. This study further investigates their impacts on decision-making leading to EHR diffusion in depth beyond breadth.

3. Influencing Factors

The factors given by the IDT that influence the decision-making related to innovation diffusion are mostly technology-related, such as relative advantage and compatibility. EHR diffusion, however, is a complex socio-technical phenomenon involving more than the technology itself but healthcare providers and other stakeholders (Nguyen et al., 2014; Gopalakrishna-Remani et al., 2019). The technology-organization-environment (TOE) framework describes the elements that influence innovation diffusion from multiple aspects (DePietro et al., 1990). Thus, this study employs the TOE framework to identify the driving factors of EHR diffusion.

Compared with personal systems, organizational systems' adoption depends more on job-related requirements than individual preferences. In the IS and management literature, how well a

technology is aligned with tasks and organizations in terms of task-technology fit and organization-technology fit largely determines how it is utilized by employees in their work (Goodhue & Thompson, 1995; Henderson & Venkatraman, 1999). To a clinic, whether to implement an EHR system and incorporate it in daily operations depends on more than the technology itself but how well it aligns with the organization's goals and stakeholders' demands.

Between a technology and an organization, the alignment comprises two levels of business integration: strategic and operational (Henderson & Venkatraman, 1999). A clinic is likely to implement an EHR system when the usage is consistent with its mission at the strategic level. At the operational level, the necessary condition for EHR adoption is that system procurement and maintenance are affordable to the organization. Between technology and organization, therefore, "business requirement" captures the EHR-clinic alignment.

Utilizing EHR on a daily basis, healthcare organizations deal with patients, pharmacies, insurances and hospitals through health information exchange (Sun & Qu, 2015). Such stakeholders comprise the EHR service environment, the integration of which through electronic workflow greatly enhances the efficiency and effectiveness of healthcare tasks (Fecher et al., 2020). Task-technology fit, therefore, embodies how well an EHR system helps a clinic handle the relationships with its stakeholders based on information processing and transmission. In this sense, "service value" pertains to the EHR-stakeholder alignment between technology and environment.

In addition to its direct connections with clinic organization and stakeholder environment, EHR technology facilitates the interaction between two. The extensive use by organizations helps them make healthcare services accessible to more stakeholders. It is found that the diffusion of EHR reduces healthcare disparity across patient ages, genders, races, and so on (Gibbons & Casale,

2010). Thus "society need" summarizes the clinic-stakeholder alignment between organization and environment.

As shown in Fig2, the alignments among EHR technology, clinic organization and stakeholder environment in terms of business requirement, service value, and society need are the main driving forces of EHR diffusion. A clinic adopts an EHR system for considerations regarding how the innovation may help it accomplish organizational goals, deal with stakeholders, and fulfill social responsibilities.

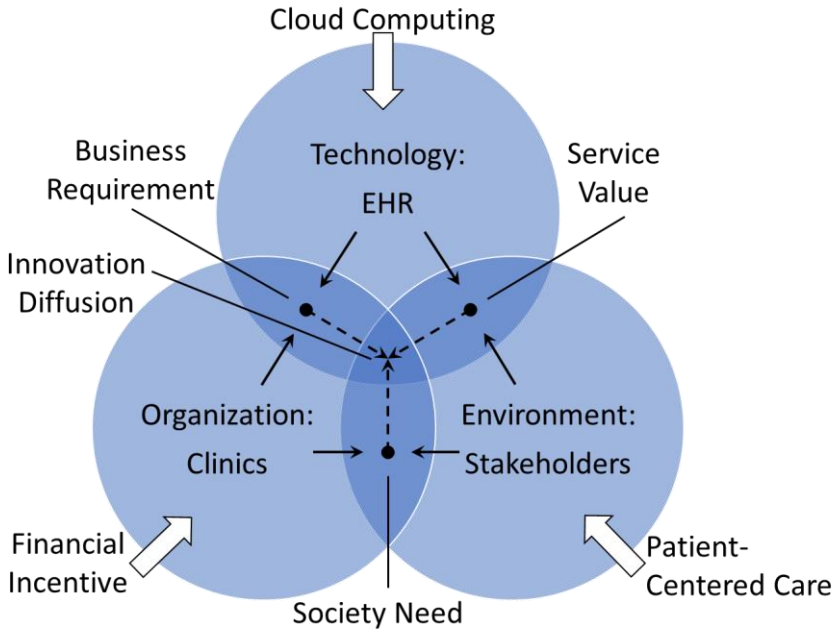

Fig2 Chain Reactions in EHR Diffusion

The speed of innovation diffusion depends on the changes in technology, organization and environment. The global diffusion of EHR is associated with the patient-centered care movement that emphasizes the central stakeholder status of patients in healthcare (Bergeson & Dean, 2006). In the case of USA, the HITECH Act provides clinics monetary incentives for the meaningful use of EHR between 2011 and 2015, after which the organizations that failed to do so face certain penalties (Burde, 2011). When cloud computing emerged as a major technological breakthrough

around 2011, it deepens EHR diffusion in addition to its breadth. How fast the diffusion is in both directions depends on the dynamics of cloud-computing, financial incentive and patient-centered care that shape the alignments among technology, organization and environment.

4. Data and Variables

The conceptualization based on IDT, TOE and alignment literature identifies the main categories of factors driving EHR diffusion in breadth and depth. For empirical evidence, this study identifies specific variables of business requirement, service value and society need, and examine their effects on EHR planning, adoption, usage and upgrade. The data were compiled from the National Ambulatory Medical Care Survey (NAMCS) between 2006 and 2016 (the latest available so far) by aggregating the original patient-level responses to clinic-level observations. Data quality was ensured by making the coding schemes consistent across years and mitigating the influence of missing data through averaging individual responses (Jetley & Zhang, 2019).

Beginning in 2004, the annual survey included questions about electronic medical records (EMR), a term used interchangeably with EHR. The bottom-line question is "Does the clinic use EMR in practice?" More items were included later, especially another question on EHR diffusion added in 2006: "Does the clinic plan to install a new EMR in the next 18 months?" This study uses the two questions as outcome variables, EHRuse and EHRplan, to capture different phases of EHR diffusion, as shown in Table 1. EHR Planning and EHR Usage are indicated with the single dummy variable corresponding to each. As previously discussed (see Fig1), EHR diffusion in depth requires usage before planning, whereas EHR diffusion in breadth does not. Thus, EHR Adoption and EHR Upgrade are indicated with both by fixing EHRuse at one level: 0 for initial adoption, and 1 for system upgrade.

Table 1. Outcome Variable Coding

Diffusion Phases	EHRuse	EHRplan
EHR Planning	N/A	0 vs. 1
EHR Adoption	0	0 vs. 1
EHR Usage	0 vs. 1	N/A
EHR Upgrade	1	0 vs. 1

As per the IDT, time is an important factor as it pertains to the innovativeness, innovation-decision process, and adoption rate (Rogers, 1995). Together, EHRuse, EHRplan and Year are the variables related to technological innovation. Out of the other survey questions, this study selects those related to business requirement (6 variables), service value (10 variables) and society need (8 variables). As shown in the Appendix, these explanatory variables capture different driving factors of EHR diffusion, and are used to predict the changes in its breadth and depth over time.

The variables under the business requirement category concern the organizational fit of EHR. For example, Solo pertains to the size of an exercise, which is associated with the resources available to the implementation and maintenance of EHR (Burt & Sisk, 2005; DesRoches et al., 2008). Private concerns the ownership structure, which also makes a difference in decision-making regarding EHR adoption (Gans et al., 2005; Menachemi, 2006). Similarly, PrimaryCare describes the nature of a practice that largely determines what kind of EHR it uses (Ash & Bates, 2005). Revenue sources directly influence a clinic's decision on whether to use EHR, especially when it is required by institutions like Medicaid and Medicare (Burt et al., 2006). Another factor is the operation involving EHR, as indicated by the time spent with each patient.

The variables under the service value category concern how EHR systems help serve patients with data collected from them and information exchanged with other stakeholders. For instance, NumMed indicates the average number of medications that a clinic prescribes to its patients, which pertains to the need for electronic prescription (e-prescription) with pharmacies as an important EHR function (Zadeh & Tremblay, 2016). Similarly, HospitalVisit and Insured

involves hospitals and insurances as other stakeholders. The rest variables concern the services to patients based on the utilization of EHR, such as chronic condition monitoring (i.e. Chronic).

The variables under the society need category are related to the healthcare disparity, which is likely to be reduced with EHR diffusion (Gibbons & Casale, 2010). Patient-wise, the variables cover major concerns including race/ethnicity, age and gender. In terms of geographic distribution, the other variables address urban-rural difference and regional development.

5. Descriptive Analysis

Fig3 illustrates EHR diffusion in the USA in terms of EHRuse and EHRplan from 2006 to 2016. Whereas EHR usage kept increasing, EHR planning peaked in 2009 and then declined. The two rates totaled 100% or more in the years of 2009, 2013, 2014 and 2015, indicating that a noticeable proportion of the clinics are upgrading their EHR systems. In 2016, the percentage of clinics planning EHR implementation dropped by one third (from 21% to 14%), probably due to the end of incentive program in 2015. Accordingly, the total fell slightly below 100%, which is normal in the long run.

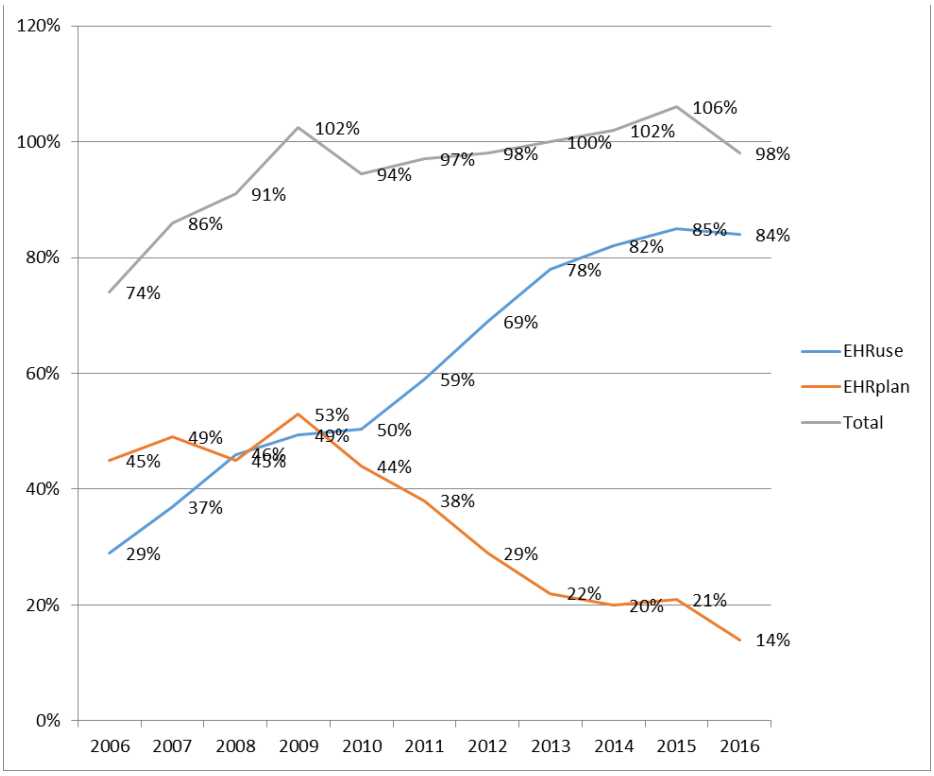

Fig3 EHR Diffusion in USA

Fig4 shows EHR diffusion in four different aspects based on the levels of EHRuse and EHRplan. The upper left box explains the rate trend of the clinics that do not currently use EHR nor plan to adopt EHR. The upper right box illustrates the rate trend of the clinics that do not currently use EHR but plan to adopt EHR, corresponding to the phase of EHR Adoption. The decreasing trends in those two boxes are consistent with the increasing rate of EHR usage shown in Fig3, as the bases of both are decreasing.

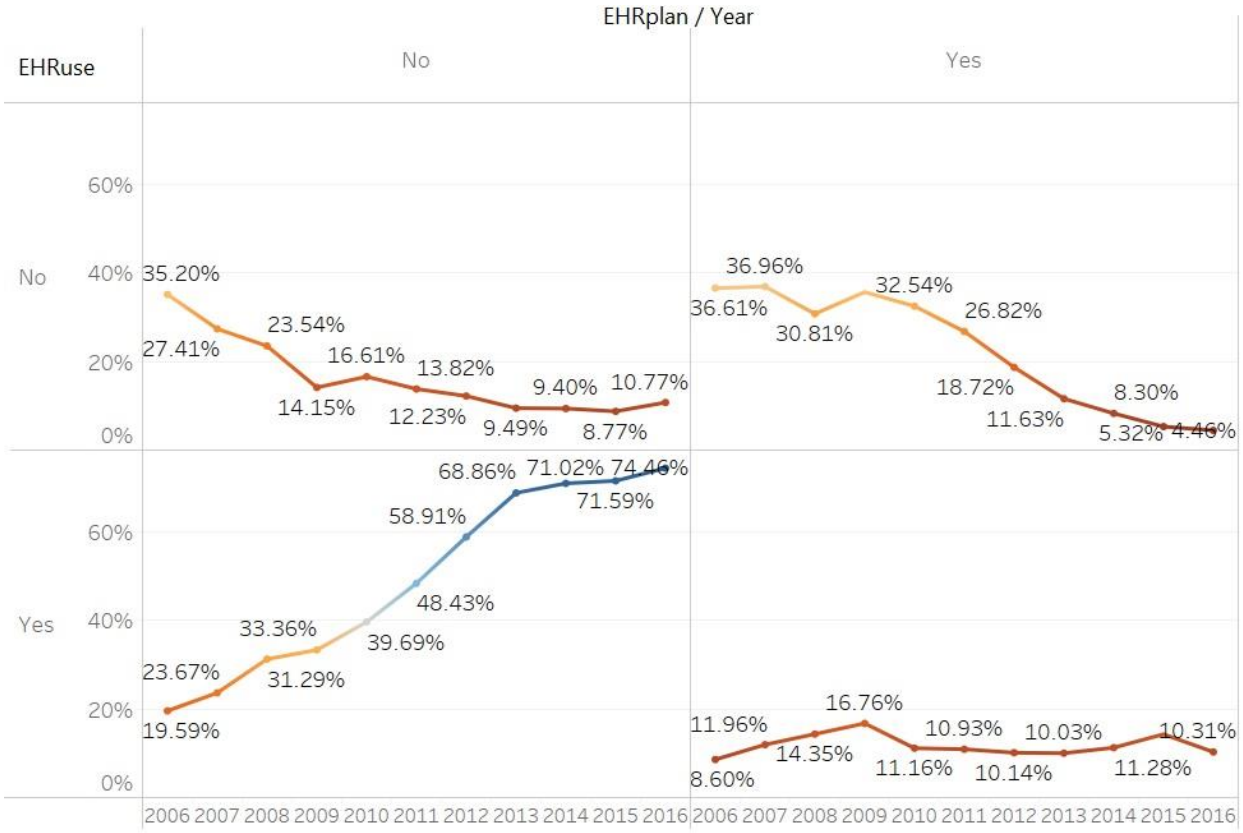

Fig4 EHR Diffusion by Quadrants

The lower boxes cover the clinics that currently use EHR. The lower left box depicts those stuck with current EHR systems for the foreseeable future, and the lower right box highlights those planning the switch to new systems, most likely cloud-based. The first trend shows the increasing rate of not planning to upgrade to new EHR systems once the clinics have made the adoption. Nevertheless, compared to the steep increase from 2006 to 2013, the rate change has significantly slowed down since 2013. That indicates a turning point that cloud-based EHR becomes more attractive as an upgrade option to many clinics recently. Meanwhile, the rate trend of EHR Upgrade remains quite steady: every year after 2006, more than 10% clinics upgrade to new systems. Thus, the cloud-based EHR market is considerable and stable for system upgrade alone in the ambulatory setting.

6. Quantitative Evaluation

Beyond the descriptive analysis, this study uses the explanatory variables related to service value, business requirement and society need to predict different phases of EHR diffusion over the years. Both outcome variables are binary, making logistic regression an appropriate tool for analyses. Since time plays an important role in innovation diffusion, the fixed effect of Year is included for controlling the heterogeneous changes over the period of observations.

In addition, split samples were obtained for 2006-2010 and 2011-2016 corresponding to the start of HITECH incentive program in 2011 and the emergence of cloud-based EHR around that time. More importantly, EHR usage in 2010 reached 50% (see Fig3), the cutoff between early majority and late majority according to IDT. Up to that point, EHR diffusion in breadth was dominant, following the sequence of planning, adoption, and usage connected with solid lines in Fig1. Beyond it, EHR diffusion in depth became prominent, as more clinics took on the route of usage, planning, and upgrade connected with dash lines. It is expected that two sub-samples yield different patterns in the relationships examined.

Table 2 reports the results of longitudinal logistic regression analyses. Across the four phases of EHR diffusion, the fixed Year variable was significant all the time for the overall sample. For the split samples, the only period in which the time trend is not very clear is 2006-10 for EHR planning, largely due to the big impact of HITECH enactment in 2009. With the overall sample, all the three categories - business requirement, service value and society need - have significant factors at each diffusion phase. The comparison between the sub-samples of 2006-10 and 2011-16 shows the latter yields more significant estimates than the former.

Table 2. Odds Ratio Estimates

	EHR Planning			EHR Adoption			EHR Usage			EHR Upgrade		
Variable	2006-16	2006-10	2011-16	2006-16	2006-10	2011-16	2006-16	2006-10	2011-16	2006-16	2006-10	2011-16
Year	1.192***	0.984	1.313***	0.950***	0.777***	1.240***	0.747***	0.810***	0.696***	1.196***	1.116***	1.099***
Solo	1.353***	1.785***	1.095	3.580	3.582***	3.694***	2.633***	2.385***	2.843***	1.134	1.134	1.138
Private	0.875	1.088	0.815	1.181	1.199	1.354	1.246**	0.862	1.615***	0.842	0.815	0.875
PrimaryCare	1.014	1.027	1.101	0.758	0.809	0.798	0.844**	0.874	0.790**	1.326	1.470*	1.177
RevMCAR	0.940*	0.947	0.907*	1.032	0.999	1.113	1.057	1.062	1.095*	0.912	0.980	0.884*
RevMAID	0.827***	0.847***	0.821*	0.825**	0.803**	0.912	1.024	1.024	1.034	0.830**	0.893	0.788***
TimeMD	1.005**	1.005	1.003***	1.013	1.010**	1.016***	1.004*	1.002	1.007**	0.995*	0.992	0.996
NumMed	1.046***	1.008	1.049	0.959*	0.910***	0.968	0.910***	0.926***	0.906***	1.032*	1.037	1.037**
HospitalVisit	0.912**	0.915	0.900	0.722***	0.819*	0.633***	0.817***	0.880*	0.776***	0.937	0.986	0.913
HomeVisit	0.975	0.837	1.034	0.926***	0.767	1.065	1.011	0.855	1.180	1.018*	0.744	1.220
Insured	1.004	0.710	1.200**	0.458	0.453***	0.403***	0.448***	0.924	0.293***	1.521**	1.728	1.432
Referral	0.976	1.004	0.938	1.103***	1.128	1.004	0.862**	0.851*	0.892	0.832	0.745*	0.879
AcceptNew	0.653***	0.569***	0.709*	0.475**	0.456***	0.512**	0.702***	0.715*	0.703**	0.724***	0.528	0.800
SeenBefore	0.663***	0.744	0.574	1.831	1.025	2.918***	3.081***	2.435***	3.807***	0.574***	0.602	0.590**
Chronic	0.979	0.892**	1.051	0.749***	0.758***	0.784***	0.750***	0.774***	0.728***	0.935	0.877	0.962
PastVisits	1.016***	1.040***	1.007***	1.023***	1.054***	1.009	1.014***	1.005	1.017***	0.997	1.012	0.988
ReturnAppt	1.051	1.176	1.141	0.847	1.196	0.734	1.096	1.136	0.978	1.451	1.251	1.497***
Hispanic	0.639***	0.805	0.522	0.595**	0.835	0.338***	1.099	1.104	1.128	0.709***	0.869	0.648*
White	1.306**	1.102	1.370***	1.246***	1.032	1.590	0.877	0.791	1.026	1.125	0.813	1.319
Age	0.994***	1.001	0.992***	1.002***	1.008*	0.994	1.013*	1.009***	1.014***	0.998	1.001	0.996
Male	1.121	1.162	1.158***	1.323**	1.434	1.253	0.906	0.711**	1.044	1.038*	0.758	1.252
MSA	1.003	1.039	0.955**	0.979	1.063	0.919	0.944	1.032	1.027	0.977	1.095	0.963
Midwest	0.991	1.165***	0.868	1.029	1.205**	0.849*	1.071*	0.937	1.195***	1.026	1.120	1.004
South	0.981	1.125**	0.882***	1.034*	1.142*	0.918	1.101***	1.028	1.157***	0.999	1.141	0.944
West	0.960	1.042	0.892***	1.033	1.182**	0.858*	1.184***	1.183***	1.189***	1.011	0.967	1.055

Note: * - Significant at 0.1 level; ** - Significant at 0.05 level; *** - Significant at 0.01 level. Business requirement: Solo through TimeMD (6 variables); Service value: NumMed through ReturnAppt (10 variables); Society need: Hispanic through West (8 variables).

Among the business requirement variables, the overall sample suggests important ones mainly for EHR Planning. This is understandable as the implementation of EHR is costly and clinics are hesitant unless it is strategically important. However, when it comes to the split samples, the 2011-16 one produces the largest number of significant variables for EHR Usage. As more and more clinics use cloud-based EHR, they see the value of fit to organizational mission and resource.

Among the service value variables, the number of significant variables decreases across the four phases of EHR diffusion in the overall sample. Once clinics have installed EHR, the use of the systems takes care of most concerns regarding stakeholders. Meanwhile, the 2011-16 sub-sample yields more significant variables than the 2006-10 one, especially for EHR Use and EHR Upgrade. To clinics, the switching from client-server systems to cloud-based solutions is a paradigmatic shift, and the enhanced interoperability has a big implication for their relationships with stakeholders.

Among the society need variables, most variables exhibit significant effects on EHR Usage with the overall sample and on EHR Planning with the 2011-16 sub-sample, with only a few on EHR Adoption and EHR Upgrade. Though society need is not of the priority concern for clinics at the adoption and upgrade phases, it does make some differences at the planning and usage phases. Whereas patient-centered care has a long-lasting influence on the equality of EHR use, cloud-computing and financial incentive are factored in for current planning. For instance, the same incentive amount means more to clinics in less developed regions due to different income levels.

In terms of each specific variable, the overall and split samples also produce different estimates, sometimes at distinct levels of significance. Among the business requirement variables, for instance, clinic characteristics in terms of size (Solo), ownership (Private) and specialty

(PrimaryCare) were insignificant in the overall sample for EHR usage, but highly significant in the 2011-16 sub-sample. Meanwhile, revenues from Medicare and Medicaid were significant for EHR Upgrade during 2011 and 2016 but insignificant during 2006 and 2010. Technology advancement pushes EHR diffusion in depth, especially when system upgrade enhances organizational fit.

Among the service value variables, average number of medications prescribed (NumMed), percentage of patients seen before (SeenBefore) and making return appointments (RetAppt) significantly affect EHR Upgrade in the 2011-16 sub-sample but not in the 2006-10 one, leading to mixed effects in the overall sample. More reuses of patient data and connections with other stakeholders (especially pharmacies) drive clinics to switch to cloud-based EHR for better information accessibility and interoperability.

Among the society need variable, Hispanic is not significant for any models during 2006 and 2010 but becomes significant for EHR adoption and EHR upgrade during 2011 and 2016. This suggests that cloud-based solutions help Hispanic-serving clinics quickly catch up in EHR diffusion (e.g., with affordable costs and bilingual features). Many other variables remain insignificant, suggesting that the technology still has a big potential in reducing healthcare disparity as the cloud market is far from being saturated.

The split-sample analysis yielded significant differences in the estimates of most business requirement, service value, and society need variables between the two periods that feature mandatory client-server EHR adoption and voluntary cloud-based EHR upgrading respectively. To assess the overall difference made by the transition from in-breadth to in-depth diffusion, this study further conducted a robustness test by creating a dummy variable: 0 for 2006-2010 and 1 for 2011-2016. Together with other explanatory variables, it was included in overall-sample analyses

to predict four phases of EHR diffusion. In addition to logistic regression, propensity score matching (PSM) and inverse probability weighting (IPW) were used as they can estimate the marginal effect of a treatment (i.e., the period dummy in this study). The results reported in Table 3 are consistent across three methods in terms of signs and significance levels, suggesting that the treatment effect of changing socio-technical environment is stable for each EHR diffusion phase.

Table 3. Estimates of Period Dummy

Diffusion Phases	**Logistic Regression**	**PSM**	**IPW**
EHR Planning	-0.453	-0.204	-0.205
EHR Adoption	0.115	0.053	0.049
EHR Usage	0.692	0.298	0.295
EHR Upgrade	-0.497	-0.177	-0.171

Note: All estimates were significant at the 0.01 level.

7. Qualitative Assessment

The quantitative evaluation is based on statistical covariations between outcome and explanatory variables and cannot "prove" causal relationships. To supplement the quantitative results, this study conducts a written interview on healthcare providers regarding their experiences with the implementation of EHR. Altogether, 37 voluntary participants were recruited from part-time students enrolled in an online master's program in health sciences. All reported the use of EHR in their clinics, of which 18 were still using client-server systems, 16 had switched to cloud-based solutions, and 3 new practices directly moved to the cloud.

Regarding the EHR technology, practitioners recognize two levels of innovation: 1) electronic records as compared with paper charts, and 2) cloud-based systems versus client-server solutions. For the first, a participant observed: "The first job I held in a healthcare organization utilized paper records, and I felt that it was overly burdensome to manage. Use of the EHR seemed like the only logical step to allow for sharing of information across disciplines. The ability to access information in an instant could be the difference between life and death for a patient." For the

second, another said: “cloud-based EHR is something that I personally agree with, simply because of the quick access to patient data on servers. In a fast-moving world, having this kind of information is definitely useful and helpful for us, but also for patients themselves and other organizations.”

Most clinics went through the migration from paper to electronic records. One participant noted the following about EHR diffusion in breadth covering planning, adoption, and usage: “In my office's transition from paper charts was extremely difficult for some physicians who needed that tangible piece of paper in their hands. But it is totally worthwhile for the improvement in the safety of patient care alone. Just think about the elimination of misread or illegible orders and notes from physicians.” About half of the clinics made the transition to cloud-based solutions. Another mentioned such EHR diffusion in depth covering usage, planning and upgrade: “Switching from in-house to cloud EHR is also a critical decision. We have used both in last few years and can clearly state how much we loved one over the other. The transition in the office was manageable depending on staff training.”

In addition to the evolving technology, the participants noted the influences of patient-centered care practice and financial incentive. “EHR provides easier access to patients and other providers for better treatment plans. Nowadays, an individual can view his/her own records via web/portal when before could only do so during office visit.” Furthermore, “While EHR was expensive to implement due to equipment and personnel training, we got financial incentives that promote the meaningful use.”

Many participants talked about the alignment among EHR, stakeholders and clinics. One pointed out: “You need to consider cost, storage, access, maintenance and training before making the switch. But first, you must decide what EHR best suites the practice. Many physicians want to

know how they will be documenting, and how much access their patients will have." Here is another observation: "Cloud-based EHR make it easier to retrieve patient records and document insurance information. To meet meaningful use criteria, physicians need to use evidence-based orders sets, ICD codes and be able to report patient registries for quality improvement. Also, they are able to send clinical information among other health care professionals electronically."

Together with quantitative results, qualitative observations yield insights on what drive EHR diffusion in both breadth and depth. Statistical and interview findings corroborate each other, and supplement the literature with an understanding of EHR diffusion mechanism that is undergoing a paradigmatic shift (Gao & Sunyaev, 2019; Sadoughi & Erfannia, 2019). As shown in Fig5, game changers in technology, organization and environment (i.e., cloud computing, financial incentive and patient-centered care) charge decision drivers from business, service and society aspects, pushing EHR planning, adoption, usage and upgrade. Rather than reaching saturation once the innovation penetrates its target population, EHR diffusion is likely to be powered by the continuous evolvement in technology and subsequent shifts in policy and practice. Even though most of the clinics have adopted EHR, they will continue upgrading their systems to catch up with emerging trends.

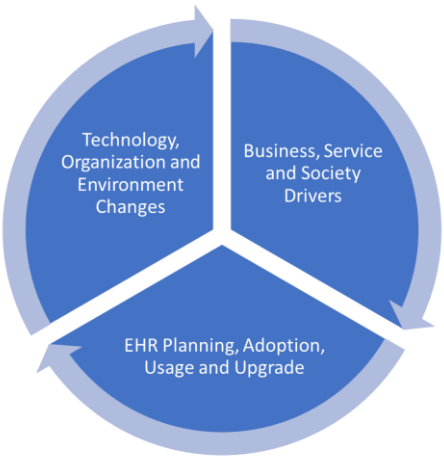

Fig5 EHR Diffusion Cycle

8. Conclusion and Implications

This study examines the paradigmatic shift of EHR diffusion in ambulatory settings under the dynamics of cloud computing, financial incentive and patient-centered care as game changers. It extends IDT by discerning the planning, adoption, usage, and upgrade phases of EHR diffusion, the different sequences among which point to two directions: breadth and depth. Based on the TOE framework and alignment literature, it identifies business requirement, service value and society need as the main decision drivers of EHR diffusion from the interactions among technology, organization and environment changes. The longitudinal analyses on the data compiled from a series of national surveys in the USA provide supporting evidence of the conceptualization. The results using overall and split samples reveal the different roles that decision drivers play at different phases of EHR diffusion. The qualitative assessment with interview observations corroborate the influences of game changers on decision-making.

The findings provide insights into how the sociotechnical phenomenon of EHR diffusion is influenced by significant events of various natures. Cloud computing, financial incentive and patient-centered care do not directly impact EHR diffusion by themselves. Rather, they lead to the adjustment in the mutual alignments among EHR technology, clinic organization and stakeholder environment that affect the decision-making of healthcare providers regarding the implementation and use of EHR. The extension of the TOE framework with alignment perspectives, therefore, helps disclose the driving mechanisms of EHR diffusion in ambulatory settings.

Most existing studies on EHR diffusion stop at adoption. However, EHR diffusion involves more than one-shot adoption but system usage and upgrade. Extending the IDT, this study examines EHR diffusion in breadth following the sequence of planning, adoption, and usage, as well as EHR diffusion in depth taking the route of usage, planning, and upgrade. The two processes

are seamlessly connected through usage and planning phases, making EHR diffusion a continuous cycle. In the original IDT, the last stage of innovation decision process is confirmation. In the current era of accelerating technology updates, it pertains to the evaluation of existing systems from usage and the comparison of potential options in planning. The iteration of system usage, planning, upgrade moves EHR diffusion to an upward spiral beyond adoption.

The advancement of technology mainly drives EHR diffusion in depth, as demonstrated by the upgrade from traditional client-server systems to new cloud-based solutions. The financial incentive on the organization side has instant and strong impacts. When the HITECH incentive program was first announced in 2009, there was a spike in clinics' intention to implement new EHR systems. But when it was ended in 2016, there was a dip. The patient-centered care movement in the healthcare environment, on the other hand, has a less dramatic but more persistent influence.

To facilitate EHR diffusion, therefore, a country may launch an incentive program to encourage clinics to implement new systems. This could quickly increase the adoption rate nationwide. However, the effect can be volatile as it quickly vanishes when the program ends. Enduring EHR diffusion in depth depends more on the advancement in technology and the demand from stakeholders. To facilitate system upgrade, EHR vendors need to provide sufficient demonstration and training to clinics.

This study has limitations that point to the direction of future research. In particular, the logistic regression used for the predictive analysis does not give the magnitude of true effect size for each variable, but mainly measures its importance. For the purpose of verifying the driving factors of EHR diffusion, this study primarily focuses on their significance levels without digging too much into specific odds ratio estimates. Nevertheless, some significant variables exhibited different effects across different EHR diffusion phases and between overall and split samples. For

instance, MSA enhanced EHR Usage in the overall sample, but weakened EHR Planning in the 2011-16 sub-sample. Whereas urban practices have more expertise and resource on hand for technology use, their rural counterparts may welcome cloud solutions and incentive programs to a larger extent. The seemingly contradictory results confirm that EHR diffusion is a complex and dynamic phenomenon. Further examination on such matters requires the use of other techniques (e.g. causative analytics) that give more accurate effect size estimates.

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Appendix. Variables Used in Analyses

Category	**Variable**	**Description**
Innovation diffusion	EHRuse	Use EHR in practice?
	EHRplan	Plan to install new EHR?
	Year	Year of Survey
Business requirement	Solo	Solo practice?
	Private	Private practice?
	PrimaryCare	Primary care provider?
	RevMCAR	% Revenue from Medicare
	RevMAID	% Revenue from Medicaid
	TimeMD	Minutes with physician
Service value	NumMed	Number of medications
	HospitalVisit	Hospital visits (last week)?
	HomeVisit	Home visits (last week)?
	Insured	Paid with insurance?
	Referral	Patient referred?
	AcceptNew	Accepting new patients?
	SeenBefore	Patient seen before?
	Chronic	Chronic illness?
	PastVisits	Past visits (12 months)
	ReturnAppt	Return appointment made?
Society need	Ethnicity	Hispanic:1; non-Hispanic:0
	Race	Caucasian:1; others:0
	Age	Years of age
	Gender	Male: 1; female: 0
	MSA	Metropolitan Area?
	Midwest	Located in Midwest?
	South	Located in South?
	West	Located in West?