A Game-Theoretic Analysis of Healthcare Information Exchanges*

In the last few years, the U.S. government has been aggressively promoting the use of electronic health records and the establishment of regional healthcare information exchanges (HIEs). HIEs facilitate electronic health information exchange among healthcare providers (HPs) that is considered to be beneficial for the society. However, the policy-makers are concerned about the sustainability of these HIEs. Based on our interactions with key personnel of different HIE providers, we present two models in this paper. The first model deals with the start-up HIEs. In the second model, we analyze established HIE providers that also offer value-added services. Although our models are developed in the context of specific HIEs, they are generic, and the results as well as insights are applicable to most of the HIE settings. Both of these models use game-theoretic framework to analyze the decisions of HPs and the HIE provider. In the first model, we find that small HPs choose not to join the HIE if there are many large HPs around them. This result indicates that it is beneficial to establish more than one HIE if the variation among HPs is high in a region. The analysis of the second model helps us study (i) the conditions when increasing the network size benefits the HIE provider, and (ii) the conditions for the new HPs to join the network. In addition, we present several other interesting insights that would be useful for both HIE providers and the HPs. We also provide guidelines for the policy-makers to improve the sustainability of HIEs.

Key words: Healthcare management, HIE networks, game theory, Nash equilibrium.

1. Introduction

Healthcare spending in the U.S. is increasing rapidly. In 2011, it grew 3.9 percent to reach $2.7 trillion (CMS 2013). More importantly, the healthcare spending accounted for 17.9 percent of nation's gross domestic product (GDP) in 2011. Therefore, the national effort on healthcare is becoming more pronounced in order to reduce costs and increase the quality of the system (Agarwal et al. 2010b, Menon and Kohli 2013). There are numerous reasons for high healthcare spending such as overuse and misuse of diagnostic testing and emergency department services, avoidable hospitalization and re-hospitalization, and fragmented information infrastructure or technology that support patient care (Mishra et al. 2012). In this paper, we focus and study the

* The bulk of the work was done by a student.

dynamics of healthcare information exchange (HIE) networks that relieve the problems due to the fragmentation of patient healthcare records or information. Patient health records are fragmented because patients tend to move from a healthcare provider (HP) to another, but their records do not move. In order for organizations to treat clinical knowledge as an organizational as well as individual property, the U.S. government is incentivizing the HIEs. These HIEs can connect HPs effectively with an estimated savings of around $80 billion at the national level (Walker et al. 2005).

Despite their promise, HIEs are still far from meeting the expectations (Agarwal et al. 2010a). Among other barriers that hinder extracting the full potential of HIE services, sustainability and other financial factors are vital (Fontaine et al. 2010, Terry 2013). Hence, HIEs around the U.S. focus on how to financially sustain their operations (Hall 2013). Agarwal et al. (2010c) also conclude that the longevity of HIEs is at question without government support. The growth and the success of these HIE networks depend heavily on the decisions taken by the HIE providers and the HPs (Walker et al. 2005). In this paper, we analyze the sustainability of the HIEs in two different environments. The proposed models are primarily based on our interactions with a number of HIEs in Texas (Calhoun 2013, Samuels 2013, Smitherman 2013). Now, in the next subsection, we briefly discuss some preliminaries and the background of HIEs.

1.1. Preliminaries of HIEs

HIEs can be defined as information sharing technology or mechanisms that automate the transfer and sharing of health-related information typically stored in multiple organizations, while maintaining the context and integrity of the information being exchanged (HIMSS 2009). An HIE provides access to and retrieval of patient information to authorized users in order to provide safe, efficient, effective, and timely patient care. HIEs are typically formed by a group of participants from a specific area or a region to facilitate the electronic exchange of health-related information. A true HIE involves multi-directional flows of information electronically among providers such as hospitals, physicians, clinics, labs, etc. Furthermore, HIE is not only about moving clinical information to the right place — it also affects the clinical workflows by making the data available to doctors and nurses when they need them to make decisions. Thus, it provides improved patient safety by sharing their medical data. In addition, cost reductions due to HIEs include elimination of duplicate tests, recovery of missing patient health data, elimination of paper, ink, and manual document printing, and reduction of phone calls and follow-ups with labs for test results. An HIE assures a strong chain of custody of patient data and their movements. It also helps in providing accurate feedback to public health registries (Fontaine et al. 2010). Finally, participating in HIEs is a requirement for HPs to receive stimulus funds (Page 2010). Now, we discuss the research questions that we study in this paper along with our contributions.

1.2. Research Questions and Contributions

In general, HIEs can be not-for-profit, public utility, physician collaborative, or for-profit (Berry and Johnson 2012). However, for sustainability, all HIEs strive for maximizing their profits. Therefore, independent of their nature, we regard the HIEs as profit maximizing organizations in our research. We study two different HIE settings in this paper. In the first setting, we focus on the dynamics of the behaviors of HIE provider and HPs when an HIE is about to be established (i.e., a start-up HIE). In this setting, the HIE is not yet established, and the price set by the HIE provider determines the number of HPs that join the network. Here, the main question we study is the following: How would the HIE set the membership fee and which HPs would join the HIE network? We derive other results and provide additional insights in this setting.

In the second setting, we study an established HIE where the HIE provider offers additional services to its members. In this setting, we examine how the HIE provider decides on the prices of different service offerings and what levels of service HPs request. In addition, we analyze the conditions for the expansion of the network. We glean several managerial insights in both settings that would be useful for the HIE provider, the HPs, and the policy-makers. Now, in the next subsection, we briefly review the related literature and highlight our contributions with respect to past studies.

1.3. Literature Review

Our study is related to two streams of literature —HIE research and game theory. In the last few years, several case studies (Fontaine et al. 2010), progress reports (Agarwal et al. 2010c), white papers (Covich et al. 2011), and surveys (Yahoo News 2012) have been published pertaining to different aspects of HIEs. As suggested in these studies, the key benefits for HPs from joining an HIE include (a) facilitation of compliance with state and federal mandates, (b) cost savings, and (c) improved quality of patient care (Fontaine et al. 2010). The HIE literature further discusses how the values gained from the HIE can be converted to a sustainable business model for an HIE provider (Marchibroda 2007). In this paper, we go one step further and analyze whether the benefits of joining the HIE outweighs the costs involved in a strategic setting with multiple HPs and an HIE provider. We form our models based on the HIE literature and our interactions with different HIE providers. Because the business relationship is among strategic players, we use game theory as our modeling approach. Use of game theory in service research is extant and well know. Hence we skip this discussion because of the space limitation.

2. HIE Scenarios

In the first model, we analyze the start-up HIEs. In order to understand the critical issues involved in the sustainability of these HIEs, we worked with a start-up HIE Southeast Texas Health Systems (SETHS) that is based in Texas. In the second model, we consider established HIE providers that also offer value-added services. and worked with two established HIE providers in Texas: Integrated Care Collaboration (ICC), and Critical Connection. Although our models are developed in the context of these HIEs, they are generic, and the results as well as insights are applicable to most of the HIE settings. Because of the space limitation, we do not provide the details of these HIEs. However, detailed discussions of these HIEs are available from the authors upon request.

3. Start-up HIE Settings

Using SETHS as an example, we develop our first model where an HIE is about to be established by a provider within a group of HPs. The total number of potential HPs that consider joining the

HIE is N. As discussed earlier, since the HIE is a start-up, its service offerings is limited to the base functionality in short to medium planning horizons. Hence, the HPs decide to join or not, but do not request additional services from the HIE provider. On the other hand, the HIE provider adjusts the price of the network subscription by taking into account how the price would affect the network size.

3.1. Model Development

Before joining the network, all HPs can estimate the net benefit they will get from the network using the methodologies mentioned in the HIE value analysis literature (e.g., Walker et al. 2005). We denote the average monthly net benefit for HP i by r_i. This parameter is the difference between the gains and the costs of joining the HIE network (adjusted to a month). The information about the net benefit r_i is private, i.e., it is unknown to the HIE provider and other HPs. However, the HIE provider can estimate the distribution of r_i based on the available information regarding HPs.

In this setting, it is reasonable to consider that r_i is independent and identically distributed (i.i.d.). All of our key insights hold with any distribution that is bounded from above and below, and most insights hold with any distribution that is unimodal. However, in order to be conservative about the variance of the distribution, we consider that r_i follows a uniform distribution with lower and upper bounds $\underline{r}$ and $\overline{r}$, i.e., $r_i \sim \mathrm{U}(\underline{r}, \overline{r})$. We would like to note that, throughout this paper, the heterogeneity refers to the variability in net benefits gained by HPs from joining the network. In particular, we measure the heterogeneity by the range of the distribution, i.e., $\overline{r} - \underline{r}$, and this measure is used in the discussion of our results.

The HIE provider sets the monthly subscription fee p. This price determines the number of HPs that join the network. Let us denote this number by K and its expected value by $\mathbb{E}(K)$. On the other hand, federal government and several other bodies reimburse a portion g of the cost of the HPs that join the network (Dixon et al. 2010). Hence, the objective function of HP i can be written as $r_i - p(1-g)$, where $g < 1$. HP i joins the network only if it receives positive value from the participation.

The HIE provider collects fees for its service from all HPs that join. Hence, the higher the price it sets, the more revenue it collects per HP that join. However, a high price for the HIE service deters the HPs as they would benefit less from joining the HIE network. Therefore, the HIE needs to balance the price accordingly that will determine the most beneficial network size. In addition to the subscription fees collected from the HPs, the HIE provider receives funds from government and other third parties. A portion of this fund is directly proportional to the network size, whereas the other portion is fixed (independent of the network size) (Covich et al. 2011). We model the network dependent reimbursement as Kf, where $f \geq 0$, and the fixed portion as J. According to Mostashari et al. (2009), the cost for maintaining the network is linearly proportional to network size. Therefore, we model it as cK, where $c \geq 0$ and $f < c$.[1] Lastly, the monthly adjusted fixed cost of establishing and maintaining the HIE network is H. In summary, the objective functions of the HIE provider and each HP, and the constraints can be written as below.

$$\max_p \; \mathbb{E}[K(f+p) - cK - H + J] \tag{1}$$

$$\text{Max}\{0, r_i - p(1-g)\} \quad \forall i \tag{2}$$

subject to

$$\mathbb{E}[K(f+p) - cK - H + J] \geq 0. \tag{3}$$

We would like to note that parameters H and J are fixed amounts, and hence they do not play any significant role in our model. Thus, in order to keep discussion and explanations concise, we set them as zero hereafter. However, the key insights remain the same with nonzero H and J.

3.2. Results and Managerial Insights

In this section, we discuss our key findings and derive meaningful insights. The HIE provider determines the price (i.e., p), and depending on this price, each HP decides whether to join the network or not. It is easy to show that p is bounded as follows: $\frac{\underline{r}}{1-g} \leq p \leq \frac{\overline{r}}{1-g}$. Based on these

[1] We also solve the problem with quadratic increasing form, i.e., cK^2. However, the key insights remain the same. Hence, we omit the detailed results for brevity.

bounds and the HPs' cost-benefit analysis, we first derive the expected network size as a function of the price set by the HIE provider (i.e., p). This result is presented in the following lemma.

LEMMA 1. *The expected network size given any price p (i.e., $\mathbb{E}[K|p]$) is equal to:*

$$\text{Max}\left\{0, \frac{\overline{r}-(1-g)p}{\overline{r}-\underline{r}}N\right\}$$

Proof: We can write the expected network size (i.e., $\mathbb{E}[K|p]$) as $\mathbb{E}[K|p] = N * \mathbb{P}[r_i - p(1-g) > 0]$. Here, $\mathbb{P}[r_i - p(1-g) > 0]$ is the probability that the network subscription would be beneficial to HP i, and N is the total number of potential HIE subscribers. We can further write: $\mathbb{E}[K|p] = N \int\limits_{p(1-g)}^{\infty} f(s)ds$, where $f(s)$ denotes the probability density function of r_i. Since r_i is distributed uniformly between $\underline{r}$ and $\overline{r}$, we can solve to get the result provided in the lemma. ■

Clearly, the expected network size decreases in network subscription price p. Next, the solution of the game that utilizes the result of Lemma 1 is trivial, hence not reported. This solution provides us with the equilibrium price of the HIE subscription presented below.

LEMMA 2. *Equilibrium price of the network service (i.e., p) is:*

(a) $\frac{1}{2}\left(c-f+\frac{\overline{r}}{1-g}\right)$ *if* $2\underline{r}-\overline{r} \leq (c-f)(1-g) \leq \overline{r}$,

(b) $\frac{\underline{r}}{1-g}$ *if* $2\underline{r}-\overline{r} > (c-f)(1-g)$,

(c) $\frac{\overline{r}}{1-g}$ *if* $\overline{r} < (c-f)(1-g)$.

The price in Lemma 2(a) is the equilibrium price, but it is valid only when $2\underline{r}-\overline{r} < (c-f)(1-g) < \overline{r}$. This is partly due to Lemma 1. The term $(c-f)(1-g)$ is a measure of the cost (adjusted with the incentives) of HIE provider for housing each participating HP. As can be seen from Lemma 2(a), when this cost parameter is between upper and lower thresholds, the HIE provider sets the price to $\frac{1}{2}\left(c-f+\frac{\overline{r}}{1-g}\right)$. This price is in between the prices depicted in parts (b) and (c) of Lemma 2. Furthermore, it is easy to observe that this price increases with the upper bound on the gain for the HPs (i.e., $\overline{r}$). Clearly, as $\overline{r}$ increases, the HIE provider increases the price in order to extract more value from the HPs. Next, in Lemma 2(b), the condition implies that the heterogeneity in terms of the net benefit the HPs expect from the HIE network (i.e., $\overline{r}-\underline{r}$) is lower than $\underline{r}-(c-f)(1-g)$. In such a case, it is better for the HIE provider to entice all the HPs to join. Hence, the HIE provider sets the price such that even the lowest gaining HP (that has value $\underline{r}$) joins. Therefore, the price is set to $\frac{\underline{r}}{1-g}$. Finally, in Lemma (2c), if the maximum gain (i.e., $\overline{r}$) is less than a threshold, it is very costly for the HIE provider to establish the network. Hence, it sets the price such that nobody joins —it can set the price higher, but no HP would join in that case neither.

Using the above results, we can determine when (i) there are no participants in the network, (ii) every HP joins the network, and (iii) a partial network is formed. We summarize these results in the following proposition.

PROPOSITION 1.

(a) There is no participant in the network when the maximum gain any HP can get from joining the HIE is small, i.e., $\overline{r} < (c-f)(1-g)$.

(b) Every HP joins the HIE when the heterogeneity among the HPs is low. Mathematically, $(\overline{r} - \underline{r}) \leq [\underline{r} - (c-f)(1-g)]$, *or equivalently* $(2\underline{r} - \overline{r}) \geq (c-f)(1-g)$.

(c) A partial network is formed (where only some HPs join) when the maximum gain any HP can get from joining the HIE is high (i.e., $\overline{r} \geq (c-f)(1-g)$*), and also the heterogeneity among the HPs is high (i.e.,* $(\overline{r} - \underline{r}) > [\underline{r} - (c-f)(1-g)]$*). These conditions can also be written as* $(2\underline{r} - \overline{r}) < (c-f)(1-g) \leq \overline{r}$. *The size of the network in this case is* $\frac{\overline{r}-(c-f)(1-g)}{2(\overline{r}-\underline{r})}N$.

Proof: If the HP that expects the most benefit from the HIE does not join, there will be no HPs interested in joining the HIE. In order to join the HIE, this HP will require $\overline{r} \geq p(1-g)$. On the other hand, the HIE provider would not be interested in establishing an HIE if the subscription fee is less than its cost minus government incentive per HP. In other words, we must have $p \leq c - f$. Analyzing these two conditions together, we reach to the result presented in part (a). Other parts of the proposition can be proved similarly, hence omitted due to brevity. ∎

Proposition 1(a) indicates that the HIEs such as SETHS need to provide separate vehicles for increasing gains for its HPs. For example, a group purchasing effort with multiple vendors (such as stationary suppliers, Internet providers, etc.) can be envisioned that can provide savings for its

HPs in regular purchases. Also, the HIE provider many times focus on the HPs that get low gains with the belief that high gain HPs will always join. However, the result in Proposition 1(a) suggests that, for sustainability, the HIE provider also needs to focus on those HPs that have high gains from joining the network. If the benefits for these HPs increase, then it helps the HIE provider in maintaining the network and sustaining the operations.

On the other hand, Proposition 1(b) shows that when the heterogeneity among the HPs is low, all the HPs join the network. Hence, for maximum number of participants in the network, the gains for different HPs should not be very different. In other words, it is beneficial to serve similar HPs from one HIE. This result provides a useful guideline for the policy-makers. If the HPs in a region are very diverse in nature, then it is advisable to have multiple HIEs in the region to support different segments of HPs. However, if the gains for HPs are similar in nature, then it is better to have a single HIE for all of them. Therefore, having SETHS's focus only on rural hospitals is a good idea for them at least in the early stages of their operations. SETHS's policy should be to develop a low-cost, high-benefit HIE that first targets high-volume paper-based HPs that do many cross-referrals. These practices have a high incentive to become electronic, but may need the low cost solution that SETHS can provide. Finally, in Proposition 1(c), we present the condition when some HPs join while others do not, depending on how much they value the network. In this part, we also provide the size of the network that is derived from the results presented in Lemmas 1 and 2. This result again reinforces the insights discussed above. In particular, the network size decreases with the heterogeneity among the HPs that is represented by $\overline{r} - \underline{r}$.

Now, based on our earlier results, we present and discuss the objective function values of the HPs and the HIE provider. In the following lemma, we present the results only for the case when a partial network is formed (i.e., the case presented in Proposition 1(c)). The results for the other two cases can also be easily derived using the earlier results.

Lemma 3. *When a partial network is formed, the values different HPs get from the HIE and the value of the HIE provider are as follows:*

(a) The value of HP i is $\text{Max}\left\{0, r_i - \frac{1}{2}(\overline{r} + (c-f)(1-g))\right\}$*, and*

(b) The value of the HIE provider is $\frac{(\overline{r}+(c-f)(1-g))^2}{4(\overline{r}-\underline{r})(1-g)}N$*.*

Proof: The results in this lemma follow from substituting the equilibrium value of the expected network size (given in Proposition 1(c)) and the price (given in Lemma 2(a)) into the objective functions of the parties (see Equations (1) and (2)). ■

The equilibrium values presented in Lemma 3 reveals several interesting results. First, there is a threshold value that determines which HPs join the HIE —if the benefit for HP i (i.e., r_i) is more than $\frac{1}{2}(\overline{r} + (c-f)(1-g))$, then HP i joins the network. From this threshold value, it is apparent that as $\overline{r}$ increases, the diversity among the HPs increases, and hence the HPs that expect low benefit levels do not join the HIE. In other words, if the upper bound of the benefits gained by HPs is high, then it is beneficial for the HPs with low benefits to stay out of the HIE network. This is because, in such an environment, the HIE provider sets a high network subscription price.

Second, the value of the HIE provider increases in both the upper bound and the lower bound on the benefits gained by HPs from joining the HIE (i.e., $\overline{r}$ and $\underline{r}$). This implies that the HIE provider extracts more value from its network if the HPs are expecting higher benefits from the network. However, the value of HIE provider decreases in the heterogeneity of HPs, i.e., $\overline{r} - \underline{r}$. Hence, it is more beneficial for the HIE provider to serve those HPs that are similar in nature. Next, we present an extension of our model where the benefits of participating HPs increase with an increase in the network size of the HIE.

3.3. Benefits Dependent on Network Size

In the base model we study in Section 3.1, we assume that either HPs do not have prior knowledge about how much value other HPs get from the collaboration or these values are independent of the network size. In other words, either they do not know the distribution of the benefit parameter r_i or this parameter does not depend on the network size. However, in some circumstances, r_i may depend on the network size and an HP may be able to estimate the distribution of r_i based on the available information about other HPs. Hence, we study this new setting that can be considered as an extension of the first model.

In this setting, the benefit any HP expects from the collaboration increases in network size. In particular, the benefit is proportional to the percentage of participants in the network (Calhoun 2013). The reason is that if there are more participants, there is more information to share. Therefore, the benefit HP i would get from the collaboration is $r_i\left(\frac{K}{N}\right)^{\beta}$. In this formulation, the power term β is more than 0 to reflect the fact that value of the HIE membership is higher in larger networks. This parameter can be set to less than 1 (resp., more than 1) to represent an environment with decreasing (resp., increasing) returns to scale with respect to network size. On the other hand, the members pay a fee that is denoted by p; and a portion g of this fee is covered by the funds supported by government and other parties. Hence, the net value of HP i in the network is $r_i\left(\frac{K}{N}\right)^{\beta} - p(1-g)$ given that there are K participants in the network. Also, the number of participants can be defined as those HPs that have positive net values. Hence, there is a recursive relationship between the net value and the number of participating HPs: $\mathbb{E}[K|p] = N * \mathbb{P}\left[r_i\left(\frac{\mathbb{E}[K|p]}{N}\right)^{\beta} - p(1-g) > 0\right]$. For the case of constant returns to scale (i.e., $\beta = 1$), we solve this equation for the equilibrium network size. Using this finding, and we derive the equilibrium price from the game that we present below. We omit the details due to space limitation.

Lemma 4. *When a partial network is formed, the equilibrium price (i.e., p) is:*

$$\frac{\overline{r}^2 + 3(\overline{r}-\underline{r})(c-f)(1-g) + \sqrt{\overline{r}^2\left(\overline{r}^2 - 3(\overline{r}-\underline{r})(c-f)(1-g)\right)}}{9(\overline{r}-\underline{r})(1-g)}.$$

Because of the space limitation, we provide only a few results from this model. Based the partial derivative of p in Lemma 4 with respect to $\overline{r}$, we present the Proposition 2 below.

Proposition 2. *When the maximum gain that any HP can obtain from the HIE (i.e., $\overline{r}$) is increased, the equilibrium price increases if the heterogeneity among the HPs is high (in particular, if $\overline{r} > 2\underline{r}$). On the other hand, if the heterogeneity among the HPs is low (i.e., $\overline{r} < 2\underline{r}$), price decreases with the maximum gain.*

Now we discuss these results and compare them with those in the base model where the benefits do not depend on the network size (see Sections 3.1 and 3.2). In the base model, the equilibrium price strictly increases with the upper bound on the gain (i.e., $\bar{r}$) (see Lemma 2(a)). An increase in $\bar{r}$ implies that the participating HPs get more benefit. Hence, one would expect that the HIE provider increases its subscription fee with an increase in $\bar{r}$ even in this case. However, as given in Proposition 2, the relationship between price and $\bar{r}$ is not monotonic. In particular, if the heterogeneity is high (resp., low), the HIE provider increases (resp., decreases) its price with an increase in $\bar{r}$. This result can be explained as follows. Increasing the subscription fee has two opposing effects: (a) increase in revenue from each participating HP, and (b) reduction in the number of participating HPs. When the heterogeneity is high among HPs, the positive effect of increasing subscription fee outweighs the negative effect, because, in this case, the HIE provider may focus only on those HPs that gain high value from joining HIE. Hence, in this scenario, the HIE provider is better off by increasing its price. However, when the heterogeneity is low, the HIE provider the HIE provider is better off by decreasing its fee with an increase in $\bar{r}$. Therefore, unlike in the base model, when the benefit information is public, diversity among HPs affect how the HIE provider should adjust the subscription fee with changes in the upper bound on the gain.

4. Established HIE Settings

In this section, we consider that the HIE is well-established and offers a spectrum of services to the participating HPs. In addition to the base services, the value-added services range from providing master patient index to longitudinal patient record viewers, and from E-prescribing to patient management tools and quality reporting (Covich et al. 2011). We analyze the equilibrium behavior of the HPs and the HIE provider in this environment and glean several useful insights. Because of the space limitation, we do not report the details here. Nonetheless, we summarize the findings in the conclusion. However, a more comprehensive version of the paper is available from the authors.

5. Implications and Conclusions

Although we could not discuss all of our findings due to the space limitation, we summarize all of our key findings in this section. In the first model, we analyze a start-up HIE setting. Here, we find the equilibrium network size and subscription fee set by the HIE provider. We also derive the conditions in order for the HPs to join a start-up HIE. We find that diversity among the HPs —in terms of how much value they expect from the network— plays a significant role in the establishment of the HIE. For example, the HPs with low gains (or small HPs) may choose not to join the HIE if there are many HPs with high gains (or large HPs) in the region. This result indicates that the HIE provider may focus on increasing the value of its services in order to entice the small HPs to join the network. SETHS has a focus on rural hospitals, and this seems to be a good practice for them at least in the early stages of their operations. Otherwise, if the HIE provider does not focus on small HPs, it may be more beneficial to establish more HIEs in the region.

On the other hand, when the large HPs want to join but the small HPs are reluctant, we recommend the HIE provider to follow one of the following two strategies. First, they can focus on small HPs in order to increase the value they get from the HIE. This would decrease the diversity among the HPs and entice more HPs to join the HIE without reducing the subscription fee too much. If increasing the value of the small HPs is very costly, the second option for the HIE provider is to focus on those HPs that value the network subscription highly (instead of calling every HP to join). However, in this case, the participating HPs face a higher price compared to that in the scenario when the HIE provider has all HPs in its network. Also, this result further strengthens our argument that there may be a need for more than one HIE in a region under certain conditions. In addition, HPs might not always know the distribution of the values obtained by their peers from the HIE membership. We show that it might be beneficial for the HIE provider to make this information public. Moreover, when the benefit information is public, diversity among HPs affect how the HIE provider should adjust the subscription fee with changes in the benefits of large HPs.

In the second model, we analyze an established HIE setting, where the HIE provider can offer other value added services. In this case, we derive the conditions for the HPs to stay in the network, the requested service levels, and the equilibrium pricing of the services. We find that even when the HIE provider is efficient in supplying higher levels of services, it may actually increase the prices of services in larger networks. Furthermore, we show that the HPs might request less services in larger networks under some circumstances. Therefore, it is not always beneficial for the HIE provider to increase the network size, because the additional service fees collected from the new HPs might not cover the loss in the fees from the existing members. Similar to the first model, these findings imply that, under certain circumstances, more than one HIE network in a region would be beneficial for the system because of the cost efficiency in smaller networks. We also find that, under certain conditions, an HP might pay a higher fee for the same level of service in a larger network but its net value actually increases. Hence, in these conditions, the HIE provider should proactively inform the HPs that they should not be deterred by the higher fee in a larger network. Moreover, we find that an HP may actually decrease its service level as the additional level of services become more valuable. Hence, while it seems important for an HIE provider to improve the marginal value for participating HPs, this strategy may be harmful in the economic sense in certain environments. In another analysis, we find that the HP reduces the service level it requests when the HIE provider is more effective in larger networks. Therefore, since these results are contrary to intuition, the HIE providers should be cautious while preparing and executing their business plans.

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