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Reducing Medicare Spending Through Electronic Health Information Exchange: The Role of Incentives and Exchange Maturity

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Abstract. Health information exchanges (HIEs) are entities that have emerged in healthcare delivery markets across the United States. By providing an interorganizational information system (IOIS) and governance over use of this system and the information exchanged through it, HIEs enable more routine and efficient electronic sharing of patient information between disparate and fragmented healthcare providers. This should result in improved quality and efficiency of care. However, significant questions persist about the extent to which HIEs produce these benefits in practice, particularly in terms of reducing healthcare spending. We use transaction cost economics (TCE) to theorize that HIEs establish a quasi-hierarchy that decreases frictions associated with information sharing in ways that reduce healthcare spending, and that the magnitude of reductions is greater when (1) insurer and provider incentives align, and (2) HIE capabilities mature. We can test these conjectures because HIEs, unlike other efforts that provide IOIS, are typically confined to regional markets and develop heterogeneously between these markets, introducing variation in insurer-provider incentive alignment and HIE maturity. Leveraging a unique national panel data set, we evaluate whether HIEs reduce spending for the largest insurer in the United States, i.e., Medicare, and whether incentives and HIE maturity modify the magnitude of reductions. We find significant spending reductions in healthcare markets that have established operational HIEs, with an average reduction of $139 per Medicare beneficiary per year (1.4% decrease) or a $3.12 billion annual reduction in spending if HIEs were nationally implemented in 2015. We also find that these reductions occur disproportionately in healthcare markets where providers have financial incentives to use an HIE to reduce spending and when HIEs are more mature. Our results inform an important open empirical question in the healthcare domain related to the value of HIEs, while also joining perspectives from TCE with the IOIS literature to understand the factors that may be relevant to IOIS value creation more generally.

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1. Introduction

Across industries, there is a value to be gained from sharing information to coordinate the actions of disparate firms, prompting researchers to investigate the value of interorganizational information systems (IOIS) (e.g., Barrett and Konsynski 1982). Despite their broad and continuing appeal, a significant gap in the literature is the issue of whether IOIS will address the significant frictions (i.e., inefficiencies surrounding the transaction process)[1] associated with the exchange of information between disparate entities (Elgarah et al. 2005, Robey et al. 2008). For instance, it is unclear whether firms participating in an IOIS will be willing to exchange information that can provide insights to other market actors about their operations or customers. We address this question and others using transaction cost economics (TCE) as a framework for identifying effective approaches for reducing frictions associated with interorganizational information sharing and creating value through IOIS, and investigating conditions that lead to heterogeneous realization of this value.

The U.S. healthcare system provides a compelling context to explore these questions because health information exchanges (HIEs) have emerged as "third-party" technology service organizations, which provide an IOIS that spans disparate healthcare providers and facilitates the exchange of medical information between them. From a TCE perspective, we argue that HIEs establish a quasi-hierarchy (Exworthy et al. 1999, Powell 1987) where the HIE acts as a formal entity that joins and coordinates the behavior of distinct market actors (i.e., providers) while allowing these actors to maintain a certain degree of autonomy and independence from the HIE. Through this quasi-hierarchy, HIEs address key frictions associated with the exchange of medical information (e.g., the manual and labor-intensive processes to locate and exchange medical information). Specifically, HIEs address these frictions by providing a shared technology infrastructure for exchanging information (i.e., an IOIS) to a wide range of unaffiliated providers, and establishing centralized governance mechanisms to oversee providers' use of the technology infrastructure and the information exchanged through it. This, in turn, improves the flow of medical information and creates value for the healthcare system. We measure HIE value in the form of reduced healthcare spending, a critical outcome given persistent increases in U.S. healthcare spending (Martin et al. 2016) and one that is sensitive to improved sharing of medical information (Walker et al. 2005). However, HIEs do not reduce all possible frictions associated with information exchange. This creates the opportunity to investigate conditions that lead to heterogeneous realization of value from HIE, i.e., incentive alignment and HIE maturity.

We leverage annual data from a seven-year period (2003 through 2009) to compare average Medicare spending per beneficiary (adjusted for regional variations in age, race, and sex)[2] in healthcare markets (Hospital Referral Regions (HRRs)) with an operational HIE relative to those without an operational HIE. Our models include market and time fixed effects, and control for relevant market-level observables (e.g., healthcare delivery infrastructure, quality performance, health information technology (HIT) adoption, patient demographics, and economic factors). We find that in healthcare markets with an operational HIE, Medicare spending per beneficiary is reduced by $139 per year, on average (a 1.4% decrease). Consistent with our theoretical framework, we find that reductions are greater in markets with stronger incentives to reduce low-value care and with more mature HIE implementations.

Our paper makes a number of contributions to the literature. First, prior applications of TCE in the information technology (IT) literature have mostly focused on IT, and by extension, the information that is exchanged through it, as an asset that supports more efficient transactions of goods or services (e.g., Bakos 1991, Gurbaxani and Whang 1991). However, this perspective does not fully consider the complex dynamics around information as a standalone good that is becoming a vital input into business processes. We fill this gap and reveal that information exchange may not always lend itself to traditional TCE approaches for reducing transaction frictions, and that significant reductions in the frictions associated with information exchange can be achieved by quasi-hierarchical approaches. Second, we can extend our understanding of transaction frictions during interorganizational information sharing and value creation to a context in which there is a third-party beneficiary from a transaction and complex relationships between market actors. As the largest payer in the United States, Medicare stands to benefit from encouraging (or even mandating) that providers use HIEs to share information and generate value, but Medicare is not directly involved in the transaction of medical information and has little ability to ensure this outcome. While settings such as this are becoming more prevalent now that the Internet has enabled network and platform structures (Schwartz and Scott 2015), to our knowledge, traditional TCE does not address the mechanisms of value-accrual when there is a third-party beneficiary. Our results reveal that value *can* accrue to third parties in these settings, particularly if they can shift more of the gains from the transaction, via modification of incentives, to those directly involved in the transaction.

Our final contribution is to the literature on IOIS and HIT value. We identify and empirically validate conditional factors in HIE value creation and address a gap in the IOIS literature pertaining to heterogeneously distributed factors that may magnify or diminish IOIS value (Elgarah et al. 2005, Feldman and Horan 2011, Robey et al. 2008). In addition, an emerging information systems (IS) literature has focused on the dynamics surrounding HIE adoption (Adjerid et al. 2015, Demirezen et al. 2016, Yaraghi et al. 2014) and value creation (Ayabakan et al. 2017, Ayer et al. 2017, Janakiraman et al. 2017). Our paper contributes to this stream of work and is, to our knowledge, the first to use nationally-representative samples and robust approaches to evaluate the impact of HIEs on healthcare spending. Because prior work has found mixed impacts of HIT on healthcare spending,[3] we also inform the literature on HIT value by showing that HIEs may have reduced spending by $3.12 billion[4] in 2015 if they were operational in all U.S. healthcare markets.

2. Background: HIEs in the Context of IOIS

Ensuring that healthcare providers have access to complete prior medical information at the point of care is necessary for optimal patient treatment. However, because of the highly fragmented nature of the U.S. healthcare system, complete information is not routinely available; most patients receive care from multiple unaffiliated providers, and as a result, portions of their medical record are distributed across the provider organizations in which they were created. As described in Section 3, organizational boundaries, as well as regulations and market incentives, create significant frictions that impede the exchange of medical information.

The challenges associated with access have resulted in HIEs emerging as a solution through which medical information is the *good* electronically exchanged across organizational boundaries. During the time of our study, there has been nearly a six-fold increase in HIEs that are actively facilitating electronic information exchange, with 13 operational HIEs in 2003 compared to 73 by the end of 2009. HIE development usually begins with a planning phase in which stakeholders decide on the governance, the technology framework through which information exchange will occur (i.e., the IOIS), and identify an initial set of provider organization participants. After major planning activities are completed, an HIE effort moves into the operational phase where it facilitates the exchange of information between its participants.

HIEs can be viewed as providing an industry-specific form of IOIS since they develop information sharing platforms that cross organizational boundaries and act as a means to connect disparate organizations to allow for more seamless, standardized, and transparent flow of digital information for efficiency and quality gains (e.g., Lee et al. 2000, Robey et al. 2008). From a business transactions standpoint, what was once accomplished via mail, fax, and telephone is conducted via *electronic* information exchange. Compared to traditional implementations of IOIS, HIEs represent an instantiation where information that is fragmented across many disparate organizations is the core good that needs to be exchanged and no physical product or service is transferred between participants. This trend can be seen in other IOIS efforts and points to the increasing role of information as a standalone economic asset.[5]

3. Realizing HIE Value Through Reduced Healthcare Spending

In this section, we take into account the features of the HIE context to argue that HIEs can generate value because they are well suited to address the frictions associated with transactions of fragmented medical information between providers. We also consider which factors moderate HIEs' propensity to reduce frictions and generate value. Specifically, we argue that routine provider access to more comprehensive medical information about their patients as well as effective use of that information results in, among other benefits, lower healthcare spending. However, because fragmented healthcare delivery results in siloed patient medical information, the information must be transacted (i.e., moved) across provider organizations and incorporated into clinical decisions for this value to accrue (see Section 3.1). Furthermore, we leverage TCE to argue that significant frictions associated with transactions of medical information limit the frequency and efficacy of these transactions (Section 3.1) and that traditional TCE approaches may be limited in addressing these frictions (Section 3.2). Finally, we argue that HIEs establish quasi-hierarchies that enable the development of IOIS as well as governance mechanisms, which mitigate these frictions and drive spending reductions through more routine transactions and use of medical information between providers (Section 3.2). However, the technology and governance offered by HIEs does not result in completely frictionless medical information exchange and use. The extent to which HIEs reduce these remaining frictions and maximize potential spending reductions depends on (1) the strength of provider incentives to reduce care that provides little value to patients, and (2) the maturity of the HIE effort (Section 3.3).

3.1. Comprehensive Medical Information Is Valuable Yet Limited by Exchange Frictions

Like human capital, supplies, and medical devices, patients' medical information is a critical input in the provision of healthcare. Comprehensive information about patients' medical history allows providers to access the relevant subset that informs the clinical decisions that drive the quality and cost of care (e.g., Lammers et al. 2013). In particular, access to needed information should result in clinical decisions that avoid redundant care, improve diagnostic accuracy, address gaps in care, and are safe. Avoiding redundant care, making diagnoses more accurate, and reducing the occurrence of medical errors should result in significant reductions in healthcare spending.

Yet, the reality is that patients receive treatment from distinct providers with diverse recordkeeping systems, resulting in siloed patient medical information (Miller and Tucker 2014). This requires that any provider seeking comprehensive patient information can routinely exchange such information with other providers. Despite the potential benefits from such exchange, routine transactions of medical information between providers is far from ubiquitous (Smith et al. 2005). Using a TCE framework, we argue that this is because sharing patient-level medical information across disparate provider organizations (what we consider the transaction) is laden with frictions. As noted by Williamson (1981, p. 552), "a transaction occurs when a good or service is transferred across a technologically separable interface." Williamson (1996) further suggests that "[o]ur understanding of complex economic organization awaits more concerted study of the sources and mitigation of friction . . . the economic counterpart for which is transaction costs" (p. 87). Moreover, frictions in transactions have been described as inefficiencies surrounding the transaction process. For example, there can be frictions that stem from transacting parties safeguarding their own interests at the expense of others, monitoring costs, communication inefficiencies, coordination costs, and costs associated with organizing information (Williamson 1981). In the context of transactions of medical information, there are two categories of frictions that hinder routine exchange, i.e., those that relate to opportunistic behavior, and those that relate to the process of exchanging and using medical information.

First, routine exchange of health information across providers is impeded by frictions related to opportunistic behavior by other market actors. TCE argues that a key friction to consider is the governance challenge associated with market actors that have potentially diverging incentives. Specifically, while organizations will seek partners and technology infrastructures in support of more efficient transactions (Williamson 1981), they will typically act in their own interest, often at the expense of the overall network (Narayanan and Raman 2004). These challenges may be pronounced when information is the core and exclusive good transacted between entities. Brynjolfsson (1993, p. 75) notes that "compared to other goods, information is particularly vulnerable to rent dissipation, in which one firm's gain comes entirely at the expense of others, instead of by creating new wealth." Specific to our context, routine exchange of medical information can place providers at a competitive disadvantage. Prior work has revealed that healthcare providers view data as a competitive asset that ties patients to their organization (Grossman et al. 2008), and that exchanged medical information can be used by competitors to poach patients and gain insight into a provider's operations and strategy. More so, routine exchange of information places organizations at risk of liability and associated reputational harm if that information is breached while in use by other providers (Pevnick et al. 2012). As a result, provider organizations may choose not to share information or put up barriers that make it costly or complex to do so, decreasing the frequency with which information is shared.

Second, there are operational frictions that impede routine exchange. Although there has been significant investment in HIT that digitizes medical information, interoperability between these systems remains a persistent challenge, forcing providers to rely on manual and labor-intensive means to locate and exchange needed medical information. Prior work estimated that billions of dollars in human capital is required to support such transactions (Walker et al. 2005). Even if providers are willing to invest the capital needed to engage in these friction-filled transactions of medical information, it is unclear whether the information would be consistently usable. For example, specific information in a patient record may be hard to find, particularly if the provider is seeking a single data point, such as a lab result, but is sent the entire record. Furthermore, the information may be presented in a format that is unfamiliar to the provider and therefore hard to interpret; for example, there are different reference values for what is considered a "normal" test result. Finally, the information may simply not be trusted, particularly if the provider believes that the organization that generated it may be of lower quality or if other information in the record suggests that there are issues with data integrity (Yeager et al. 2014).

Together, these opportunistic and operational frictions contribute to the reality in most healthcare markets that medical information is not routinely exchanged, and when it is exchanged, it occurs via one-off market transactions in which a provider coordinates with another provider to exchange medical information in an ad hoc fashion for a specific patient encounter. The result is information exchange at a level far below what is required to provide comprehensive information access to providers, leaving significant potential value unrealized.

3.2. HIEs: Alternatives to Ad Hoc Market Transactions for Medical Information Sharing

The status quo for transacting medical information (i.e., ad hoc market transactions) is clearly inadequate. This is not surprising. Williamson (1979, p. 241) notes that ad hoc market transactions have "seriously defective investment incentives" that do not provide "the assurance of a continuing relation... needed to encourage investments" in assets that improve the transaction efficiency. TCE suggests that reducing these frictions requires a shift towards the appropriate coordination model. In particular, when market transactions occur frequently, TCE advocates pursuing a more systematic approach that includes contractual agreements that establish long-term relationships between individual market actors. However, under certain conditions where monitoring and control are limited, a hierarchy is preferred where transactions are within a firm and governed by employment relationships, supervision, control, routines, and formal, bureaucratic rules. In other cases, a hybrid approach that falls between the two can be more appropriate (Exworthy et al. 1999; Powell 1987, 1990). This choice depends on the degree of asset specificity (i.e., how unique an asset is to a particular transaction), bounded rationality/uncertainty surrounding the transaction, and the frequency of transactions (Williamson 1981).

We first consider the option of a modified market-based approach that includes contracts that ensure long-term commitments between individual market actors. This option has some advantages over ad hoc market transactions since it can motivate the development of assets in support of more efficient transactions. However, scholars note that governance mechanisms for market transactions can break down if assets that support the transaction are highly specific to that transaction (Williamson 2005), which is the case in our context. Specifically, the good transacted is medical information in digital form, which requires some form of IT infrastructure between otherwise disconnected providers. Because providers, even within the same medical system, typically have incompatible IT infrastructures that create costly interoperability challenges, the IT assets developed in support of market transactions are likely to be highly specific to each provider (Bakos 1991). Limitations of high asset specificity are compounded by the high frequency of transactions needed to achieve comprehensive information access for providers, and by bounded rationality that results in "unavoidably incomplete" market contracts (Williamson 2000, p. 601). Under these conditions, developing contracts with market-based partners is complex, time consuming, and requires frequent monitoring and negotiation (Williamson 1985). Of course, the fragmentation of medical information requires each provider to negotiate terms and establish highly specific IT assets not just with a single provider, but with multiple providers to achieve reasonably comprehensive information availability.

These dynamics suggest that information sharing between provider organizations would be more appropriately coordinated by some *type* of hierarchical structure. Under a hierarchy, a common technology infrastructure can be established for all providers and the central governance structure can reduce opportunistic behavior. However, the fragmented nature of care in healthcare markets (and by extension patient data) would require an impractically large and costly hierarchical governance structure in which all records were maintained by a central actor under a single entity (e.g., Williamson 1981). Prior work substantiates this notion and argues that pure hierarchical approaches can be infeasible when partners are numerous, distal, and connected at varying degrees (Exworthy et al. 1999, Powell 1990).

With a pure hierarchical approach being potentially useful but not operationally or financially feasible, HIEs offer the next best model, i.e., a hybrid model described by scholars as a quasi-hierarchy.[6] Quasi-hierarchies are characterized by the existence of a formal entity that seeks to coordinate the behavior of distinct market actors while allowing these market actors to maintain a certain degree of autonomy and independence from the hierarchy (Exworthy et al. 1999; Kickert et al. 1997; Powell 1987, 1990; Thompson et al. 1991). HIEs align with scholars' conception of quasi-hierarchies since they are stand-alone and formal entities that seek to join and coordinate transactions of medical information by coordinating the behavior of distinct healthcare providers. At the same time, providers choose whether to join the HIE, retain their independence from the HIE even after joining, and maintain ownership over their own data. Consistent with other quasi-hierarchies, HIEs have diminished control over providers' behavior relative to a pure hierarchy (Exworthy et al. 1999). That said, HIEs can still offer governance mechanisms that are demonstrably better than what is offered by the status quo of ad hoc market transactions. Allowing providers to participate in an HIE while maintaining their autonomy overcomes the key challenge of traditional hierarchical approaches and is also key to achieving broad participation.

Through this quasi-hierarchical approach, HIEs reduce the frictions described in Section 3.1 in two key ways. First, HIEs can serve as a common technical framework between a wide range of fragmented providers, which facilitates the identification and retrieval of patient information across disparate systems, significantly reducing the need for high-specificity IT assets between disconnected providers. For example, HIEs often allow a provider to search for and retrieve any existing information about their patient that may exist in the electronic record systems of other providers. In many cases, HIEs provide a web portal to exchange information that only requires an Internet connection and a browser, i.e., IT assets with extremely low specificity. While the IT assets provided by HIEs clearly reduce the frictions associated with the *transmission* of medical information, they can also reduce frictions associated with the *use* of medical information. Specifically, the technical infrastructure offered by HIEs often serves to standardize health information in terms of the document format (such as a clinical summary record that contains predefined headings and field-level entries, such as "medications" and "problems"), and in more advanced cases, standardizing the vocabulary that is used. Moreover, outside information can be more easily integrated into the patient's record if it is transmitted electronically and electronic information may be more easily searched and used. The combination of these factors makes it more likely that information is seen and used by providers.

Second, the quasi-hierarchical approach taken by HIEs enables them to create and implement centralized mechanisms for managing the behavior of participants and help curb opportunistic behavior. Specifically, as the "center" of a quasi-hierarchy involving different providers in a market, HIEs can bring together otherwise disconnected providers to negotiate and agree on terms related to the use of a shared technical infrastructure as well as the information exchanged through it. While it can be difficult to gain agreement from all parties, once specified, agreed upon terms can address the concerns of diverse providers in a market and extend well beyond what is offered by federal and state

Figure 1. Excerpt of HIE Data Use Agreement

"data recipient shall not use Patient Data, the Services or the System to aggregate data to compare the performance of other Participants and/or Authorized Users for competitive purposes" ... "[the HIE] *may terminate a Participant's Registration Agreement upon written notice in the event the Participant's acts or omissions adversely affect the stability of or inhibit the efficient operation of the network or the health information exchange."*

regulations (which are typically focused on protecting sensitive health information). These terms are usually formalized via contractual agreements between HIE participants that then become key mechanisms for curbing opportunistic behavior from participating providers. For example, these contractual agreements specify, among other things, approaches for exchanging data, boundaries around acceptable use of exchanged data, how to assess liability if a breach occurs, and technical and administrative protocols of exchange (see Figure 1 for an excerpt of a data use agreement from a large regional HIE, who chose to remain anonymous).

HIEs, as the center of the quasi-hierarchy, can then execute these agreements with various providers and hold them liable if any breaches occur. Although the contractual agreements used by HIEs may still be "unavoidably incomplete," generating consensus on these agreements through a quasi-hierarchy is likely to result in agreements that better account for the diverse concerns of different providers in a market. As a result, HIEs can offer considerable improvement over ad hoc transactions of medical information in their ability to oversee providers' behavior and curb opportunistic behavior.

Therefore, HIEs significantly reduce the frictions associated with transactions and use of medical information, making providers in markets with an HIE more likely to have access to comprehensive, timely, and usable health information from other provider organizations. When providers have such access, a strong professional obligation to deliver the best care (Pevnick et al. 2012, Yeager et al. 2014), as well as reputational considerations (Davis et al. 2010) should motivate use of newly available information to make better clinical decisions. Improved clinical decision making should result in significant reductions in healthcare spending when providers can avoid redundant care, improve diagnostic accuracy, and avoid medical errors. Prior research supports such benefits from HIEs: Bailey et al. (2013) finds that HIEs were associated with reductions in repeated diagnostic imaging for back pain; Lammers et al. (2013) finds that HIEs were associated with a reduced probability of repeat CT scans, ultrasounds, and chest x-rays; others find that HIEs were associated with lower rates of admissions (Vest et al. 2014) and readmissions (Vest et al. 2015). We therefore hypothesize that:

Hypothesis 1 (H1). *In healthcare markets that establish an operational HIE, there will be reductions in average spending per patient.*

3.3. Contingent Effects of HIE Value

Even though HIEs reduce frictions associated with transactions in ways expected to reduce healthcare spending, they may not do so to the fullest extent possible. First, while HIEs reduce frictions associated with opportunistic behaviors between providers, some opportunism still may persist because of the structure of healthcare payments in which there is a third-party, e.g., Medicare (and other insurers), that is peripheral to the HIE and does not participate in information exchange but realizes the benefits when HIEs reduce healthcare spending. This introduces the potential for opportunistic behavior, not between participating providers, but by providers towards Medicare in which they act in ways that do not maximize spending reductions (Walker et al. 2005). Second, while the technology infrastructure provided by HIEs reduces frictions associated with sharing and usability of information, there are still non-trivial frictions associated with accessing incomplete information and incorporating even usable medical information from HIEs into provider workflows (Unertl et al. 2012). These remaining frictions suggest that the spending reductions that HIEs generate would not be homogenous if factors that alleviate these two types of frictions emerge to different degrees across healthcare markets with HIEs. We first argue that reimbursement contracts in markets that shift risk for healthcare spending to providers can diminish the motives for opportunistic behavior by providers towards insurers, leading to more routine use of information and thus further reducing spending. Then, we argue that HIE maturity can diminish frictions stemming from incomplete information and workflows that do not ensure routine use of the information made available by the HIE.

3.3.1. Aligning Incentives to Reduce Opportunistic Behavior and Increase Effective Use of Information. IOIS implementations, like HIEs, that involve diverse market actors who are not actively engaged in the central transaction but realize benefit from it can introduce additional frictions for creating value. With HIEs, insurers benefit the most from the use of HIEs but have little control over whether these savings accrue because the reductions depend on the behavior of the focal users of HIEs, i.e., healthcare providers. From Medicare's perspective, HIEs address many of the frictions that hinder the exchange of medical information. However, the frictions that HIEs address are those between individual providers, and not those between providers and insurers. Specifically, although contracts associated with HIE include mutually agreed upon terms of use that limit the liability and opportunistic behavior between *participating providers*, Medicare is not typically a participant. Even if terms were included in these agreements related to insurers, they would be impossible to enforce since insurers cannot observe or judge effective use of HIEs by providers. In essence, as the largest insurer in the nation, Medicare has the most to gain from HIEs, but HIEs do not provide the capability for them to directly influence whether providers use exchanged information to make better care decisions that reduce spending (Cross et al. 2016).

We expect this to create frictions stemming from opportunistic behavior that limit spending reductions when Medicare reimburses providers under the traditional fee-for-service. Providers that are paid fee-for-service would lose revenue if they use HIEs to make better care decisions that result in them providing less care (e.g., avoiding duplicative testing). Therefore, providers may be opportunistic in their use of information exchanged through the HIE and only use it when they can reap much of the benefit. For example, a provider may use HIEs to avoid repeating a lucrative test only if that test is painful or risky to the patient (i.e., they accrue some ethical, reputational or quality gains), but not otherwise.

This suggests that mechanisms outside of those controlled by HIEs could unlock further spending reductions in markets with an HIE. A stream of research within TCE suggests that incentives can be offered as a means of better aligning diverging interests of participants and thus reducing transaction costs (Gurbaxani and Whang 1991). For example, when there are asymmetric benefits in an exchange, the affronted party can choose to renegotiate the contract. However, TCE explicitly notes that contract renegotiation is a very costly friction that increases transaction costs. In situations like these, another more cost-effective solution is for the more powerful partner to offer incentives for participation (Williamson 1985). Feldman and Horan (2011, p. 190) argue that there must exist a means of creating "blended value" for all parties. In the context of HIE, provider and insurer financial incentives can be better aligned by shifting from fee-for-service reimbursement to capitated reimbursement. By contrast to fee-for-service, which compensates based on the number and intensity of services provided, capitation shifts the financial risk of care to providers by giving them a fixed sum to deliver all needed care to the patient. If the cost of care provided exceeds the fixed sum, the providers take the loss, and if the cost of care provided is less than the fixed sum, they keep the difference. Compared with traditional fee-for-service reimbursement, capitated reimbursement should result in providers being more motivated to avoid redundant and unnecessary care, and subsequently more likely to use the information made available through HIEs.

Similar forces may operate at the provider organization level. Provider organizations that are predominantly paid on a fee-for-service basis may be less able to justify a significant investment in developing new workflows that ensure that providers see information made available through the HIE. Specifically, new workflows take longer because of the added time to search for and incorporate new information; this may not only result in avoiding care for which the organization is reimbursed but also requires time that is taken away from reimbursable patient care (i.e., fewer visits or less time to deliver care during visits). If, instead, the organization has at least some patients for whom they receive capitated reimbursement, they would directly profit from avoiding test duplication and not feel as much pressure to maximize the number and intensity of visits. This would increase the likelihood of workflow redesign to ensure that newly available information from the HIE is seen and used by providers. In accordance with TCE, we argue that incentives, in the form of capitated reimbursement, will reduce opportunistic behavior by providers and, in turn, increase the magnitude of spending reductions from HIE. We therefore hypothesize that:

Hypothesis 2 (H2). *Healthcare spending reductions due to operational HIEs will be greater in healthcare markets with higher rates of patients covered under capitated insurer contracts.*

3.3.2. HIE Maturity as a Means of Increasing Effective Use of Information. Frictions associated with the use of HIEs will diminish over time as HIE capabilities and coverage matures and as providers' workflows change to accommodate newly available information, holding incentives constant. A central tenet of TCE is that, as the transacting frequency increases, firms should seek additional benefits afforded by hierarchical structures (Williamson 1981, 1991). This is particularly relevant to HIEs and other network technologies since their capabilities and usefulness improve as they engage a growing number of participants (Narayanan and Raman 2004) and, as a result, the number of transactions increases. Typically, HIEs become operational with a handful of key strategic partners actively exchanging a limited set of valuable information (e.g., lab results) and HIEs then expand the quantity and quality of information by including more partners. Thus, there is a persistent friction of providers seeking information that is not available or not being shared by other providers. Besides wasting time for a particular clinical transaction, a derivative effect of this experience may be to discourage future attempts to seek information from the HIE. In addition, some clinical decisions require complete medical information and even one missing piece can necessitate redundant utilization. As more complete information is available over time, we expect that these frictions would be reduced.

Even when comprehensive information is available, additional work is required to incorporate it into provider workflows and decisions. That is, provider organizations must still invest in ensuring that newly available information from an HIE is *used* by providers. These changes in provider workflow, necessary to realize spending reductions from HIEs, take time to implement. In addition, providers must learn to assess the quality of the information from other organizations to decide how to incorporate it into their clinical decisions. Over time, providers participating in an HIE learn to use the functionality provided by HIEs (e.g., how to query data from the HIE), and to incorporate information seeking into their workflows and decisions. In accordance with TCE, as the frequency of transactions increases and the frictions associated with transactions decrease over time, the magnitude of benefits will increase. We hypothesize:

Hypothesis 3 (H3). *The magnitude of healthcare spending reductions from operational HIEs will increase over time.*

4. Data

Our empirical approach to assess the impact of HIEs on healthcare spending for Medicare beneficiaries leverages a seven-year panel data set (2003–2009). Our focal outcome measure of healthcare spending comes from the Dartmouth Health Atlas (DHA). Because HIEs have emerged as regionally focused efforts,[7] we use measures of healthcare spending at the level of a state subregion. Specifically, we use HRRs as our unit of analysis because they represent regional health care markets determined by the geographic boundaries in which most of the residents received major cardiovascular surgical and neurosurgical care (Wennberg and Cooper 1999). In effect, HRRs are precisely defined to capture the geographic region in which a patient is likely to receive the bulk of their care, thus requiring the sharing of medical information enabled by an HIE among providers in an HRR.

The DHA measure of Medicare spending relies on a 20% random and representative sample of Medicare beneficiaries and captures average yearly Medicare spending per beneficiary in a given HRR. This is an aggregate measure that includes reimbursements for charges originating from hospitals, physicians, outpatient facilities, hospice care, home health, and purchase of medical devices. All spending measures are adjusted for variation in age, sex, and race over time and between regions based on the distribution of the national Medicare population (The Dartmouth Atlas of Health Care 2014). In the adjustment method, national spending for each age-sex-race category is computed. These rates are then applied to the HRR population to produce the expected spending in the HRR (i.e., the spending that would have occurred in the HRR if it's spending were the same as the national amount). This approach helps to adjust spending for the varied distributions between regions and across time in the types of patients and the severity of their medical conditions.

To identify HIE activity, including the calendar year in which each HIE began to plan for exchange, when it became operational, and the HRRs in which it operates, we drew on two national sources. The first is the eHealth Initiative (eHI) list of HIEs (eHealth Initiative 2010), which publishes an annual directory of planning and operational HIEs in the United States. We compiled the names of all HIEs that ever indicated being operational in any year of eHI's annual survey between 2003 and 2009; this yielded 88 HIEs. Because eHI does not release data on HIE characteristics (e.g., when they became operational or the specific HRRs in which they operate), this initial list of operational HIEs was used to conduct a detailed national survey of HIEs (Adler-Milstein et al. 2011), which captured a more complete snapshot of HIE activity as of the end of 2009. This second source provided granular data on the number of months that HIEs had been planning and operational and the HRR in which each HIE operated. Because the survey did not achieve a 100% response rate, combining the two sources yielded usable data (i.e., with data on when they became operational and their market of focus) for 73 HIEs or 83% of operational HIEs identified by eHI.[8] On average, operational HIEs in our data set had been exchanging health information for 3.5 years. In terms of participation levels from healthcare providers and patient coverage, the snapshot of HIEs revealed that most had achieved meaningful coverage by 2009: On average, HIEs had roughly one-third of the hospitals in their market (7/20) participating, and 38% of the HIEs in our data set exchanged health information for more than 500,000 patients by late 2009 with an additional 43% of operational HIEs exchanging information for between 50,000 and 500,000 patients. Twenty percent of HRRs were covered by at least one operational HIE by late 2009; 77% of these HRRs were covered by only one operational HIE. No HRRs had more than two operational HIEs.

To test our hypothesis about the conditional effect of provider financial incentives, we used data from the Area Health Resources File (AHRF) to create an annual measure of the penetration of capitation-based reimbursement in the HRR. Specifically, we measure the HRR-level Medicare Advantage (henceforth "MedAdv") penetration rates.[9] A MedAdv plan is a type of health plan offered by a private company that contracts with Medicare to provide all benefits.[10] This data was not available in the AHRF in 2006 and 2007, so these years are excluded from our analysis to evaluate the effect of MedAdv penetration. We also do not observe the specific capitation rates set in each market. While MedAdv includes a range of plans

Table 1. Correlation Between Time Operational and HIE Maturity

Variables	Description	Time operational (continuous)	Time operational (median)
AmbProviding	Percent of ambulatory care facilities in the region providing data	0.24***	0.19
		(0.08)	(0.17)
AmbReceiving	Percent of ambulatory care facilities in the region receiving data	0.37*	0.31**
		(0.01)	(0.02)
HospProviding	Percent of hospital beds in the region providing data	0.35*	0.35*
		(0.01)	(0.01)
HospReceiving	Percent of hospital beds in the region receiving data	0.32**	0.27**
		(0.02)	(0.04)
HighPatient	HIE with 50,000–500,000 patients or over 500,000 patients covered	0.21***	0.25**
		(0.08)	(0.03)

Note. p-values are in parentheses.
$^{*}p < 0.01$; $^{**}p < 0.05$; $^{***}p < 0.10$.

that accept capitated reimbursement, they are predominantly Health Maintenance Organizations (approximately 65%) and Preferred Provider Organizations (approximately 35%).[11]

To test our hypotheses about the conditional effect of HIE maturity, we leveraged the panel nature of our data set to evaluate lagged effects of operational exchanges. To help ensure that this measure is detecting the hypothesized mechanisms, we used our cross-sectional data on HIE characteristics (captured only for 2009, the final year of our panel data) to explore whether the length of time an HIE is operational correlates with other measures of HIE maturity (e.g., percentage of providers in a participating healthcare market and the magnitude of patients covered by an exchange; see Table 1).

Finally, we used a number of additional data sets to generate HRR-level controls. First, we used the Healthcare Information and Management Systems Society (HIMSS) Analytics Database[12] to capture the variation in regional hospital HIT adoption over time. We capture the percent of hospitals in an HRR adopting a Clinical Data Repository (CDR) and Computerized Physician Order Entry (CPOE): Independent of HIEs, these systems have been shown to lead to reduced healthcare spending (Tierney et al. 1993). We used the AHRF to capture the variation in healthcare delivery infrastructure between regions and across time. This includes the number of hospitals, nursing homes, and home health agencies in a region; and the number of hospital staffed beds, the number of inpatient days, and the number of outpatient visits for a given region. Also, we used the AHRF to capture the differences in patient demographic factors (e.g., population, individuals over 65, individuals per square mile), and economic factors (e.g., unemployment rate and per capita income), between regions and over time. To aggregate this data to the HRR level for analysis, we follow Fu et al. (2013) and use the "zip code to HRR crosswalk" files provided by the DHA alongside the zip code-to-county crosswalks provided by the Department of Housing and Urban Development to create a weighted average for each variable depending on the overlap of the HRR with a particular county. Finally, we used DHA data to capture the variations in healthcare quality indicators between HRRs (mortality and discharge rates), and data from the Centers for Medicare and Medicaid Services (CMS) to capture variations in the case mix index and wage index between HRRs and over time (see Table 2).

4.1. Estimation

We test H1 by estimating the effect of operational HIEs ($OperationalHIE_{jt}$) on average Medicare spending per beneficiary ($MedSpend_{jt}$) using a panel Ordinary Least Squares (OLS), fixed effects model, and heteroskedasticity-robust standard errors. Specifically, we estimate the following main model:

$$\begin{aligned} MedSpend_{jt} &= \beta_1 \cdot OperationalHIE_{jt} + \delta \cdot HealthIT_{jt} \\ &\quad + \alpha \cdot HealthcareMarket_{jt} + \zeta \cdot HealthcareQuality_{jt} \\ &\quad + \gamma \cdot Demographic_{jt} + \theta_j + \lambda_t + \mu_{jt}. \end{aligned}$$

$MedSpend_{jt}$ is the age, sex, and race adjusted average Medicare spending per beneficiary in HRR j at time t. These adjustments effectively control for any variation in beneficiary age, sex, and race mix across regions in our estimation. We also evaluate the impact of operational HIEs on the natural log of average Medicare spending. This allows us to evaluate the percentage change in Medicare spending per beneficiary due to operational HIEs. Moreover, this adjusts for any deviations from normality in the distribution of Medicare spending, which are common in healthcare spending measures and may impact the efficiency of our OLS estimation (although this is less of a concern since Medicare spending data are already regional averages and thus largely normal). $OperationalHIE_{jt}$ is a dummy variable indicating whether an HRR j had an operational HIE at time t. $HealthIT_{jt}$ is a vector of controls for

Table 2. Summary Statistics

Variables	Description	Panel	Cross-section
Medicare Spending	Age, sex, race adjusted average reimbursement per Medicare beneficiary	\$7,773 (1,492)	\$9,061 (1,411)
Operational HIE	Binary indicator for whether an HRR has an operational HIE	0.0868 (0.282)	0.199 (0.400)
Medicare Enrollees	The number of Medicare beneficiaries in an HRR with qualifying charges	85,525 (77,300)	81,895 (75,575)
CDR Adoption	Percent of hospitals in the HRR adopting CDR	56.6 (25.3)	79.8 (18.0)
CPOE Adoption	Percent of hospitals in the HRR adopting CPOE	14.4 (16.6)	23.2 (19.1)
Number of Home Health	The number of home health organizations in an HRR	3.045 (5.943)	2.116 (4.389)
Number of Nursing Homes	The number of nursing home facilities in an HRR	28.53 (50.29)	34.32 (71.03)
Hospital Inpatient Days	The total number of hospital inpatient days in an HRR (1,000)	790.4 (902.4)	777.9 (878.3)
Population	The population in an HRR (1,000)	975.8 (1,095)	1,002 (1,130)
Population Over 65	The number of individuals over the age of 65 (1,000)	122.4 (126.1)	129.2 (132.7)
Per Capita Income	The per capita income of individuals in an HRR (1,000)	32.32 (8.402)	35.97 (7.878)
Unemployment	The number of unemployed individuals in an HRR (1,000)	28.77 (35.90)	46.49 (55.53)
Population per Square Mile	Population per square mile in an HRR	823.6 (3,529)	837.7 (3,595)
Medicare Discharge Rates	The number of hospital medical discharges per 1,000 Medicare enrollees	235.1 (44.16)	224.7 (41.91)
Medicare Mortality Rate	Age, sex, race adjusted % of deaths among Medicare enrollees	4.995 (0.504)	4.676 (0.471)
Medicare Advantage	Percent of Medicare beneficiaries with Medicare advantage coverage	12.53 (11.73)	19.68 (11.07)
Wage Index	Measure capturing differences in the regional cost of healthcare labor	0.983 (0.134)	0.983 (0.162)
Case Mix Index	The diagnosis-related group (DRG) relative weight for all hospitals in an HRR	1.364 (0.112)	1.38 (0.110)
Formal	An indicator variable for whether the HIE in an HRR has a formal structure by 2009	— —	0.881 (0.326)
HighPatient	An indicator variable for whether the HIE in an HRR includes more than 50,000 patients by 2009	— —	0.831 (0.378)
TimeOperational	The number of months an HIE in an HRR has been operational	— —	45.03 (47.48)
Observations[a]		2,142	306

Note. Standard deviations are in parentheses.
[a]Medicare Advantage data was not available in 2006 and 2007, thus the number of observations decreases to 1,530 when included.

regional adoption of CDR and CPOE among hospitals which, as described above, may result in reductions in healthcare spending in and of themselves, and may also encourage the pursuit of HIE efforts by increasing the amount of electronically captured health information that could be exchanged. $HealthcareMarket_{jt}$ is a vector of controls capturing the key elements of regional healthcare markets that may influence the propensity of regions to have an operational exchange and Medicare spending. For instance, $HealthcareMarket_{jt}$ controls for the number of medical providers of different types over time and between regions, as this may be correlated with the emergence of HIEs but may independently impact Medicare spending. Moreover, we control for any effect of changes in capacity that may impact spending between regions and over time with variables for hospital care capacity in an HRR. We use a measure of total hospital inpatient days to capture hospital care capacity. This measure strongly correlates ($\rho > 0.8$) with measures of the total number of hospitals, total outpatient visits, and total staffed beds in an HRR. We also include measures of secondary healthcare providers in a region by controlling for the number of nursing home and home health organizations. These organizations are considered key future partners for HIE development and may also independently impact Medicare spending (Newhouse et al. 2013). This vector also includes a control for the number of Medicare enrollees within a region to account for markets with larger Medicare populations.

$HealthcareQuality_{jt}$ is a vector of controls that captures changes in quality of care across healthcare markets over time. This may be relevant if regions with higher quality medical providers are also more likely to pursue HIE efforts. For example, higher quality medical providers may make fewer medical errors or be less likely to provide redundant care, but may also be more likely to pursue HIT initiatives. As a result, $HealthcareQuality_{jt}$ includes controls for medical mortality rates and medical discharge rates between regions and over time. $Demographic_{jt}$ is a vector of controls for regional demographic and economic factors that accounts for variations in patient populations between markets and over time; these go beyond the age, sex, and race adjustments reflected in our spending measure.

HRR and time fixed effects are represented by θ_{js} and λ_t, respectively; μ_{jt} is the error term. HRR fixed effects allow us to control for time-invariant factors that could simultaneously drive the emergence of HIEs and changes in Medicare spending. For instance, regions with nationally recognized healthcare delivery systems (e.g., the Geisinger Health System) may be more likely to pursue HIEs and may also have lower Medicare spending per enrollee. Also, differences in the market structure between regions beyond those we could directly measure, which tend to be reasonably time-invariant over shorter periods of analysis, may impact the emergence of HIEs and Medicare spending. Time fixed effects allow us to control for time trends in our data. Thus, the unbiased effect of operational HIEs on Medicare spending can be identified from variations across HRRs and time.

Next, we estimate an extended model to test whether HIEs have a heterogeneous effect on Medicare spending (H2). We test whether penetration levels of MedAdv coverage in a healthcare market moderate the impact of HIEs on Medicare spending. Since we hypothesize that spending reductions from HIEs would be larger in markets with higher levels of MedAdv penetration among beneficiaries, we add to our main model a measure of MedAdv penetration (*MedicareAdvantage*) in a healthcare market[13] and the interaction between *OperationalHIE* and *MedicareAdvantage*. In this extended model, a positive and significant coefficient on the interaction would support our hypothesis.

Finally, we evaluate the role of time in moderating the impact of *OperationalHIE* on Medicare spending (H3). We estimate a variant of our primary model that includes relative time dummies with indicators for each of the two years preceding an HIE becoming operational to identify pre-trends in our estimation, an indicator for the year it becomes operational, to capture the initial effects of the HIE becoming operational, and indicators for each of the two years after the HIE becomes operational to identify lagged value.

5. Results

Our main estimation results are presented in Table 3. We find support for H1, with operational HIEs resulting in a reduction in the average Medicare spending per beneficiary in a healthcare market. In an initial estimation with HRR and time fixed effects (but excluding other controls), we find a \$91 reduction ($p < 0.05$) in Medicare spending from HIEs (Table 3, Column 1). In our primary specification, in which we also include our full set of controls (Table 3, Column 2), we observe larger and statistically significant estimates of reduced spending due to HIEs. Specifically, we find that HIEs resulted in a \$139 decrease ($p < 0.01$) in spending per beneficiary. Our results are consistent when we use the natural log of Medicare spending, with a statistically significant ($p < 0.01$) 1.44% decrease in Medicare spending per beneficiary (Table 3, Column 3).

In most specifications, we included a number of control variables that may be related to operational HIEs and Medicare spending. Healthcare market capacity controls tended to be positively correlated with average Medicare spending. We find that higher inpatient days, number of home health agencies, and higher hospital discharge rates were associated with increased Medicare spending. The wage index and case mix index typically did not predict spending. Increased adoption of HIT in a region did not have a significant effect on spending. Last, some differences in patient demographics between regions and over time had a significant effect. For instance, greater population density and higher unemployment resulted in higher Medicare spending, while increased income was associated with lower spending.[14]

Next, we examine the impact of MedAdv penetration on the magnitude of spending reductions (H2) and begin by evaluating the concern that operational HIEs are correlated with MedAdv (which directly impact Medicare spending) by controlling for MedAdv penetration.[15] We find that the negative relationship

Table 3. Effect of Operational HIEs on Average Medicare Spending per Beneficiary

	(1) Fixed effects	(2) Fixed effects and control	(3) Log of spending	(4) Medicare Advantage	(5) Medicare Advantage	(6) Relative time
Operational HIE	−91.21**	−138.6*	−0.0144*	−157.2*	−17.74	
	(43.60)	(35.69)	(0.00409)	(43.97)	(72.93)	
Medicare Advantage				−3.579	−3.268	
				(3.789)	(3.769)	
Operational HIE × Medicare Advantage					−7.203**	
					(3.471)	
OperationalHIE ($t-2$)						6.244
						(30.75)
OperationalHIE ($t-1$)						−35.91
						(33.42)
OperationalHIE ($t=0$)						−86.06**
						(33.73)
OperationalHIE ($t+1$)						−100.8**
						(40.48)
OperationalHIE ($t+2$)						−124.4*
						(37.86)
Hospital inpatient days (1,000)		0.327**	3.57e−05**	0.409***	0.450**	0.319**
		(0.145)	(1.64e−05)	(0.219)	(0.219)	(0.148)
Number of nursing homes		4.022	−0.000475	5.551	6.174***	4.370
		(3.399)	(0.000444)	(3.731)	(3.661)	(3.392)
Number of home health		5.651*	0.000150*	5.647*	5.628*	5.727*
		(0.888)	(4.93e−05)	(0.828)	(0.825)	(0.890)
Medicare mortality rate		−55.30	0.00505	−100.3	−101.4	−56.10
		(52.18)	(0.00746)	(61.50)	(61.84)	(51.82)
Medicare discharge rates		4.498*	0.000621*	4.002*	3.983*	4.444*
		(1.076)	(0.000112)	(1.241)	(1.239)	(1.079)
CDR adoption		−6.251	0.00555	−17.54	−9.711	−10.03
		(59.71)	(0.00657)	(70.90)	(70.99)	(60.04)
CPOE adoption		57.05	0.00599	66.86	71.83	51.77
		(69.85)	(0.00739)	(83.06)	(82.59)	(70.39)
Observations	2,142	2,142	2,142	1,530[a]	1,530	2,142
Controls	No	Yes	Yes	Yes	Yes	Yes
HRR FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Note. Robust standard errors are in parentheses.
[a]Medicare Advantage data was not available in 2006 and 2007, thus the number of observations decreases to 1,530 when Medicare Advantage is used in our model.
$^{*}p < 0.01$; $^{**}p < 0.05$; $^{***}p < 0.1$.

between operational HIEs and lower Medicare spending persists, with slightly larger and significant estimates of spending reductions (\$157, $p < 0.01$) (Table 3, Column 4). When we introduce an interaction, *OperationalHIE* × *MedicareAdvantage*, we find evidence supporting our hypothesis. Specifically, we find an insignificant main effect on *OperationalHIE*, but a significant negative coefficient (−\$7.2) on the interaction ($p < 0.05$, Table 3, Column 5). This suggests that cost savings are driven by regions with higher levels of MedAdv penetration, with an additional savings of roughly \$7 per beneficiary for every percentage point increase in MedAdv penetration.[16]

Finally, we examine our hypothesis that cost savings from an HIE will be impacted by the length of time it is operational (H3). We first leverage our relative time model to evaluate simultaneity or reverse causality concerns in our estimation; rather than operational HIEs driving reduced Medicare spending, reduced spending may be driving the emergence of operational HIE efforts. For example, healthcare providers who are focused on efficiency may be more likely to pursue HIEs and may already be trending towards lower Medicare spending per patient, independent of HIEs. We investigate these concerns using indicator variables for one and two years prior (see Chan and Ghose 2014) to an HIE becoming operational *OperationalHIE* ($t-2$) and *OperationalHIE* ($t-1$). We find that both have small and insignificant coefficient estimates suggesting that a problematic pre-trend in our data is less likely

(Table 3, Column 6). Next, we evaluate the potential lagged effects of HIE on reductions in Medicare spending and find support for H3 with the benefits of HIE increasing over time (Table 3, Column 6). Specifically, we find a spending reduction from HIEs of $86 in the initial year of operation ($p < 0.05$), a $101 decrease in spending in the second year of operation ($p < 0.005$), and a $124 decrease in spending in the third year of operation ($p < 0.01$).

6. Robustness

We evaluated the robustness of our primary results by examining concerns about (1) estimation bias and the endogeneity of operational HIEs, (2) alternate explanations of our effect, (3) measurement of central constructs, and (4) the possibility that a single market, state or year could be driving our results.

6.1. Estimation Bias

A central concern with this type of analysis, which uses secondary data, is that estimates will be biased due to endogenous variables of interest being correlated with the error term in the estimation. This can happen in a number of ways, including simultaneity or reverse causality (which we considered in our relative time model from Section 5), and omitted or unobserved variable bias. In our context, the emergence of operational HIEs is certainly not random and may be endogenous through a correlation with other factors that could also impact Medicare spending in a region, thus presenting risks to the causal interpretation of our results. For example, systematic differences in healthcare markets (e.g., cost of healthcare inputs or quality orientation of leadership in healthcare delivery organizations) may exist between markets in which HIEs emerge and reach operational status and those in which they do not. Moreover, HIE efforts may be correlated with other healthcare provider efforts to improve the efficiency and efficacy of care. These may include changes to hospital operations that reduce costs and improve the quality of patients' care (e.g., a move towards lean processes), which could result in lower utilization and associated Medicare spending.

Our estimated model partially addresses these concerns through (1) healthcare market and time fixed effects that isolate the impact of time trends and time-invariant differences between markets, (2) a broad set of controls to capture relevant observables, and (3) an age, sex, and race adjusted measure of Medicare spending to address variations in the severity of beneficiaries between healthcare markets and over time (McGinnis et al. 1987). However, because endogeneity concerns may persist, we further reduce these concerns through a combined strategy of estimating our model using a propensity score matched (PSM) sample, falsification tests, and additional adjustments to our measure of spending that account for differences in the cost of healthcare between markets.

First, we use a PSM approach to estimate our model on a subsample of our data that more closely mimics the randomized assignment of operational HIEs (Rosenbaum and Rubin 1983). This well known method leverages relevant observables to identify a control group of non-treated observations (i.e., healthcare markets without operational HIEs) that would have been most likely to have been treated (i.e., to have had an operational exchange). A comparison of pretreatment trends between markets with and without operational HIEs reveals some differences (see Table 4), suggesting that a PSM approach could be useful in reducing some of this disparity. In particular, markets

Table 4. Propensity Score Matched Sample

Variable	Treatment	No treatment (full sample)	|Bias|	p-value	No treatment (matched)	|Bias|	p-value	Kolmogorov–Smirnov
CDR Adoption	0.54	0.56	0.02	0.43	0.53	0.01	0.78	0.88
CPOE Adoption	0.12	0.14	0.02	0.42	0.12	0	0.95	0.94
Number of Home Health	35.75	26.63	9.12	0.22	30.25	5.5	0.58	0.67
Number of Nursing Homes	4.6	2.73	1.87	0.04	4.72	0.12	0.94	0.66
Hospital Inpatient Days	1,379.54	657.51	722.03	< 0.0001	1,118.49	261.05	0.40	0.23
Population	1,602.68	817.65	785.03	< 0.0001	1,390.11	212.57	0.54	0.31
Population Over 65	201.29	102.76	98.53	< 0.0001	181.74	19.55	0.63	0.29
Per Capita Income	32.57	31.71	0.86	0.4561	33.25	0.68	0.71	0.75
Unemployment	43,593.23	23,868.94	19,724.29	< 0.0001	38,346.57	5,246.66	0.60	0.58
Population Per Square Mile	2,241.81	515.19	1,726.62	0.002	668.31	1,573.5	0.29	0.14
Medicare Enrollment	274,500.1	147,390.8	12,710.23	0.0001	24,226.46	3,223.61	0.49	0.16
Medicare Discharge Rates	231.01	237.8	6.79	0.3	227.75	3.26	0.75	0.61
Medicare Advantage	11.99	14.82	2.83	0.07	16.56	1.74	0.48	0.86
Medicare Mortality Rate	4.99	5.03	0.04	0.67	4.93	0.06	0.47	0.25
Wage Index	1	0.97	0.03	0.11	1.01	0.01	0.74	0.70
Case Mix Index	1.35	1.36	0.01	0.55	1.35	0	0.95	0.71

Table 5. Estimation Bias

	(1) PS – Medicare spending	(2) PS – Log Medicare spending	(3) PS – Medicare spending (Caliper = 0.01)	(4) PS – Log of Medicare spending (Caliper = 0.01)	(5) Planning HIE	(6) Price adjusted	(7) Log of price adjusted	(8) HRRs with HIE	(9) Operational HIE
Operational HIE	– 100.2** (38.79)	– 0.0109** (0.00431)	– 129.5** (49.46)	– 0.0144* (0.00514)		– 161.9* (38.34)	– 0.0136* (0.004)	– 84.36** (39.14) (32.48)	– 73.96**
Planning HIE					– 2.812 (14.20)				
Observations	714	714	532	532	2,142	2,142	2,142	686	427
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HRR FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes. PS, Propensity score matched. Robust standard errors are in parentheses.
$^{*}p < 0.1$; $^{**}p < 0.05$.

with operational HIEs tended to be considerably larger with more inpatient days, nursing homes, and Medicare enrollees. We perform a nearest neighbor match with replacement using a Probit model and matching each treated observation to one untreated observation to create a control group for markets with exchange. A comparison of the pre-treatment trends for the PSM shows considerably less disparity between the treated and control group suggesting that the matching is addressing some of these concerns. Using this matched sample, we replicate our main results and find consistent results: Operational HIEs reduced healthcare spending by $100 per Medicare beneficiary or 1.1% (Table 5, Columns 1 and 2). We refine this analysis by setting a caliper of 0.01 to restrict our analysis to only treated markets where a close match could be made and find even stronger results: Operational HIEs resulted in a $130 reduction (1.4%) in spending (Table 5, Columns 3 and 4).

In addition to the PSM strategy, we leverage some features of our data to further reduce concerns around potential bias. First, we leverage the fact that HIEs have a period after they have been initiated in which they are *planning* for exchange and are *not yet operational* and estimate the impact of HIEs during this period. If the pursuit of HIEs is correlated with unobserved factors that are driving the reductions in Medicare spending, we may expect that the benefits of these factors would be observed before HIEs become operational. As expected, there is a non-significant effect of HIEs that are in the planning phase on spending (Table 5, Column 5).

Medicare relies on administered pricing, therefore the spending measure in our analysis essentially reflects differences in the types of services, utilization, and increases in payments for certain services based on nationally updated "weights." Specifically, Medicare reimburses providers for hospital admissions based on diagnostic-related groups (DRGs). This introduces a potential omitted variable bias if operational HIEs emerge in regions where the cost of living is not increasing as fast as other healthcare markets: We may simply be misidentifying the changes in reimbursement rates as cost savings due to operational HIEs. While this is partially addressed by controlling for the Wage Index in our original specification, we go further by using Medicare spending data adjusted for differences in DRG weights between healthcare markets and over time (Skinner et al. 2011), effectively accounting for the variation in the cost of healthcare delivery between regions and over time (Gottlieb et al. 2010). Using this revised "price-adjusted" measure, we continue to find significant reductions in spending as a result of operational HIEs, i.e., a $162 (1.36%) reduction in spending per beneficiary (Table 5, Columns 6 and 7).

Finally, although not directly related to endogeneity concerns, we conduct additional robustness checks related to the potential of markets with exchanges to be qualitatively different from those without. Specifically, healthcare markets with an HIE may also be different with respect to how other covariates in the model relate to Medicare spending, which could bias our estimates. For example, healthcare markets with operational HIEs may have Medicare spending that is not growing as fast as healthcare markets without an exchange. In this case, the estimate on *OperationalHIE* may be driven by this difference in time trend between healthcare markets. To alleviate these concerns, we evaluate the impact of operational HIEs on spending relative only to other HRRs that have a planning exchange during our period of analysis. Despite restricting our analysis to less than one-third of our original data set, we continue to find a statistically significant $84 reduction in Medicare spending ($p < 0.05$) due to operational HIEs (Table 5, Column 8). We further restrict our analysis to the healthcare markets with only operational HIEs and effectively estimate a before and after effect of an operational HIE in these markets (Table 5, Column 9). Again, we find a statistically significant reduction in spending (\$74, $p < 0.05$).

6.2. Strategic Hospital Behavior

One potentially confounding phenomenon in our context is the ability of providers in healthcare markets to shift their mix of patients. In particular, providers may act strategically to decrease or increase the care of patients that are more or less profitable for them, which would be driven by the type of insurance coverage of patients in a given market. We address this concern in two ways. First, we evaluate whether markets in which HIEs emerged impacted the volume of hospitals' care of Medicare beneficiaries, defined as the number of Medicare inpatient days divided by the hospital's total inpatient days. This data comes from the American Hospital Association and was available for all U.S. hospitals in the three-year period from 2007–2009. These years coincided with the modal years for HIEs reaching operational status. We estimate a similar model to our main estimation except that we use hospitals' Medicare proportion as the dependent variable and we include fixed effects at the hospital level instead of the market level. Including hospital fixed effects represents a robust estimation approach since they also capture the higher order market fixed effects (hospitals do not change markets). Using this model, we find that operational HIEs do not impact hospitals' Medicare proportion (Table 6, Column 1) and this effect persists when we include a control for MedAdv penetration (Table 6, Column 2). Finally, we include the interaction between *OperationalHIE* and *MedicareAdvantage* (Table 6, Column 3) and continue to identify an insignificant effect of the interaction on hospitals' Medicare proportion. This suggests that the main effect of HIE, as well as the differential effect in markets with higher rates of capitation, is not explained by shifts in hospitals' care of Medicare beneficiaries.

In addition to this analysis, we consider the potential of market competition to provide a cleaner mechanism for identifying our effect. Specifically, more monopolistic markets provide less opportunity for the shifting of care by providers across patients with different insurance. Therefore, we calculate the Herfindahl–Hirschman index (Herfindahl 1950) for all markets using 2008 data from the American Hospital Association on hospital size (number of beds) to identify the more monopolistic markets in our data (parsed by the median value of the index). We then evaluate the impact of *OperationalHIE* in these markets while parsing between markets with high versus low levels of MedAdv penetration, again split at the median (Table 6, Columns 4 and 5). We find that *OperationalHIE* continues to have a significantly different effect depending on rates of MedAdv penetration even in highly monopolistic markets.

6.3. Sensitivity Analysis

Our analysis thus far has assumed that HRRs are independent observations. However, most HRRs' coverage is exclusively or predominately within a single state. As a result, they may not be independent observations, leading us to overstate the precision of our estimates. On the other hand, HRRs have been precisely defined to identify distinct healthcare markets, in which case HRRs could be independent, even within the same state. We address this issue by estimating our model using state-clustered standard errors and find consistent and statistically significant ($p < 0.01$) reductions in spending (Table 7, Column 1).

Another potential issue is that we have thus far considered a healthcare market as having an operational

Table 6. Hospital Switching and Competition

	(1) Hospital inpatient days	(2) Hospital inpatient days	(3) Hospital inpatient days	(4) Low competition and high Medicare Advantage	(5) Low competition and low Medicare Advantage
Operational HIE	0.00150	−0.0114	−0.0179	−242.0*	51.36
	(0.00751)	(0.00868)	(0.0194)	(91.14)	(82.18)
Medicare Advantage		0.0130**	0.0131**		
		(0.00528)	(0.00533)		
Operational HIE × Medicare Advantage			0.000276		
			(0.000687)		
Observations	16,828	11,116	11,116	390	375
Controls	Yes	Yes	Yes	Yes	Yes
Hospital FE	Yes	Yes	Yes	No	No
HRR FE	No	No	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Note. Robust standard errors are in parentheses.
$^{*}p < 0.1$; $^{**}p < 0.05$.

Table 7. Sensitivity Analysis

Variables	(1) State clusters	(2) Multiple HIEs	(3) Multiple HIEs	(4) No overlap	(5) HIE characteristics	(6) HIE characteristics
Operational HIE	−138.6* (36.95)		−141.8* (34.89)	−135.46* (36.69)	−25.408 (46.41)	342.6** (144.6)
Operational HIE (continuous)		−94.45* (30.62)				
2nd operational HIE			28.08 (51.85)			
Operational HIE × *TimeOperational*					−4.36** (2.049)	−2.493* (0.955)
Operational HIE × *TimeOperational*^{2}					0.0141 (0.008)	
Medicare Advantage						−2.946 (3.831)
Operational HIE × *Medicare Advantage*						−8.117** (3.192)
Operational HIE × *Formal*						−271.2** (134.7)
Operational HIE × *High Patient*						−31.63 (93.98)
Observations	2,142	2,142	2,142	2,121	2,142	1,520
Controls	Yes	Yes	Yes	Yes	Yes	Yes
HRR, Year FE	Yes	Yes	Yes	Yes	Yes	No

Note. Robust standard errors are in parentheses.
$^{*}p < 0.1$; $^{**}p < 0.05$.

exchange if it had at least one HIE operating. However, 14 markets had two HIEs operating by the end of our data set. Therefore, we relax this binary assumption and estimate the effect of a continuous measure of operational HIEs (Table 7, Column 2). In addition, we add to our original model an indicator for when a second exchange becomes operational (Table 7, Column 3). Neither of these estimations alters our main result, with a significant negative effect of *OperationalHIE* on spending. Note that the main effect using a continuous measure is somewhat diminished and that an additional operational exchange potentially diminishes the value of an HIE (although insignificant). Although not conclusive, these results suggest some reduced value when multiple HIEs are operational in a single market. This would be in line with the dynamics of HIEs since competing operational exchanges in a single market likely limit the ability of any one exchange to reach the critical mass of patient data and provider participation to create more value. In addition, we consider whether our attribution of HIEs to a single market that had significant coverage in another market (while rare) could be impacting our results in a meaningful way. Specifically, we estimate our model by excluding the markets that had more than 25% of their geographic coverage in another healthcare market and find consistent results (see Table 7, Column 4).

We also estimate a model that includes some additional controls for HIE characteristics; because the measures of HIE characteristics were only captured in the final year of our data, this analysis is only suggestive but provides an additional robustness check for our results. We find results consistent with a lagged effect of HIE with a significant and negative coefficient on the interaction of *OperationalHIE* and the months an HIE has been operational (*TimeOperational*). We find a positive (although insignificant) coefficient on the square of *TimeOperational* suggesting some nonlinearity in this effect (Table 7, Column 5). In addition, we estimate a full model including measures to capture differential effects of operational HIEs by rates of *MedAdv* penetration as well as the interaction of *OperationalHIE* with indicators of whether an HIE had a formal structure by the end of 2009 (*Formal*), whether HIEs covered more than 50,000 patients by the end of 2009 (*HighPatient*), and the months they were operational. Again, we find that our results for H2 and H3 are robust, with statistically significant effects of the interaction of *MedAdv* and *OperationalHIE*, and a significant and negative effect on *TimeOperational* (Table 7, Column 6).

Finally, we evaluate whether data from an individual HRR, state or year is driving our observed results. This could be the case if HRR-, state- or year-specific shocks occur during our study time period that impact HIE development and Medicare spending in that state. For instance, a state may pass legislation that dedicates significant resources to reducing healthcare spending, including establishing HIEs. We address this concern by reestimating our primary model while sequentially excluding individual HRR, state, and years of data. We find that our results are robust to this test, with a tight distribution of t-statistics around a mean of −3.8 (the main effect never falls out of significance), revealing consistently statistically significant and negative estimates on *OperationalHIE*.

7. Limitations

While we attempted to ensure the robustness of our results through the approaches described, some limitations remain. For example, our data do not enable us to directly examine the mechanisms through which HIEs reduce Medicare spending. Instead, we use prior literature to theoretically develop mechanisms through which HIEs reduce spending. The benefits of a quasi-hierarchy point to the potential for HIEs to reduce frictions that exist in the market by, for example, decreasing duplicative care when prior patient medical information from other providers is more readily available (Ayabakan et al. 2017). It also helps explain why the magnitude of the reduction may vary across markets with different provider reimbursement structures and implementation maturity. However, we cannot directly assess the mechanisms for value creation. We face this limitation because, to our knowledge, no longitudinal, national data exists that captures provider interactions with HIEs in markets (i.e., how much information is shared, when it is incorporated into provider workflows and decisions). Relatedly, our analysis does not account for the cost of developing and participating in an HIE, because we did not have access to national cost data.

We also recognize that operational HIEs in the United States are not yet ubiquitous, resulting in less variation in HIE activity than would be empirically ideal and raising concerns about generalizability. However, we do observe a reasonable variation in our data as well as meaningful overall levels of HIE penetration, with nearly 20% of the healthcare markets having an operational HIE and nearly 40% of the healthcare markets having a planning or operational HIE. Also, the time frame of our analysis captures an early period of HIE development and may not reflect the gains from today's HIEs, which may be more sophisticated in technology, governance, usability, and scope. Studying HIE activity in an early time period before federal policy intervention, however, holds some advantages. First, the gains from HIEs that we identify are likely to be conservative relative to gains after HIEs become more established. Second, between-market comparisons are more feasible since HIEs are still largely operational in a single market during this time period. A final limitation of our analysis is that the savings we identify are only those realized by Medicare and thus our results may not generalize beyond Medicare. Other insurers may realize larger (or smaller) relative savings than we observe due to differences in patient demographics and the resulting degree of fragmentation in their care. Relatedly, we do not observe specific capitation rates under MedAdv, and therefore cannot address how rates set at specific levels may impact the magnitude of savings. Finally, while we take a number of precautions to rule out issues of unobserved factors and selection between healthcare markets, we acknowledge that these concerns may persist as they often do with empirical work of this nature.

8. Discussion

These limitations notwithstanding, we identify statistically significant and economically meaningful reductions in average annual Medicare spending per beneficiary due to HIEs. This suggests that the dynamics promoting effective use of information in clinical decisions made available by HIEs prevail, on average. However, greater savings result when provider incentives are better aligned through shifting the risk for the cost of care as well as when HIEs have time to mature.

8.1. Theoretical Contribution

These findings inform the broader IOIS literature and add to TCE in a number of important ways. First, as noted by Malone et al. (1987), IT can be a key enabler of hybrid forms of organizational coordination, and while it has been a forgone conclusion that they create value, until now, the mechanisms of value creation had not, to our knowledge, been articulated. We develop a theory to explain how HIEs, as quasi-hierarchies that provide an IOIS and centralized governance mechanisms, reduce frictions associated with interorganizational data sharing and use, even though this hybrid form provides only limited control over market actors. Second, we extend interorganizational information sharing theory by addressing a scenario in which there is a third party actor that does not directly participate in exchange but benefits from it. The current literature points to several scenarios under which third parties can benefit (or suffer) (Schwartz and Scott 2015), but it does not empirically investigate benefit accrual. We not only describe and empirically examine this scenario, but we use it as the basis to explore the conditions under which IOIS value creation may be greater. Specifically, we argue that incentive alignment will motivate providers to act in ways that increase value when they directly realize part of the resulting value. Together, these contributions can be characterized as (1) revealing avenues through which value can accrue from information sharing governed by a quasi-hierarchy; (2) highlighting the opportunity to use HIEs (and the complex interplay of incentives in which they operate) to understand the role of financial incentives and maturity in IOIS value creation (Tzeel et al. 2011), and (3) drawing attention to the fact that HIEs represent a new form of IOIS in which the value proposition is less certain because information is the primary focus of exchange and exchange partners are only loosely affiliated.

8.2. Implications for Healthcare

These findings have important implications for healthcare stakeholders as they clarify a pressing open question about HIE value and inform a path forward in the ongoing debate about how to approach HIE in a sustainable way by clarifying the magnitude of benefits that accrue to payers and the conditions that generate greater benefits. There is widespread agreement on the value that *could* be generated from the nationwide pursuit of HIEs, but little clarity on the magnitude of value and the stakeholders to whom value accrues. Without such information, it is difficult to know how best to approach HIE. Specifically, since the direct beneficiaries of healthcare cost savings are insurers, providers have balked at covering the costs associated with HIE participation. Insurers, however, have been reluctant to support HIEs because they are not convinced they will realize benefits because they have no mechanism to ensure that providers use newly available information from HIEs to make better decisions, particularly when there are financial disincentives to do so under fee-for-service payment (Cross et al. 2016, Goedert 2009). This leaves many HIEs struggling to secure the investment needed to become operational, determine who benefits, and establish a fair approach to the allocation of costs.

By providing robust evidence that HIEs lead to spending reductions, our findings help reassure insurers that a business case can be made for their support and offer insight into the magnitude of benefit. Our results suggest that the healthcare markets that had an active HIE in 2009 saw an approximate $1 billion in total spending reductions as a result of HIEs (spending $74.01 billion instead of $75.05 billion, or a 1.4% reduction).[17] Extrapolating these results to relevant subtypes of Medicare spending in 2015 in the United States (i.e., the $240 billion in federal Medicare spending related to hospitals, physicians, outpatient facilities, hospice care, home health, and purchase of medical devices),[18] suggests that HIEs could have reduced spending by $3.12 billion (1.4% of $240 billion) if they were implemented in all markets. These are likely conservative estimates since they do not account for the growing value of HIEs over time and their potential effects on other types of Medicare spending. These results complement studies that have assessed savings from HIEs in local markets, such as Vest et al. (2014) that calculated an annual savings of $357,000 from avoided admissions, and Vest et al. (2015) that found an annual savings of $605,000 from avoided readmissions, both from an HIE in Rochester, New York. Lammers et al. (2013) calculated an annual savings of $2.8 million from HIE in the emergency department setting as a result of avoiding redundant imaging (they use data on patients from California and Florida). Other works that consider savings nationally (which is closer to our empirical setting) suggest that our paper identifies only part of HIEs' potential value. For example, Walker et al. (2005) estimate that nationwide information exchange could yield as much as $80 billion in annual savings; Jha et al. (2009) estimate that HIEs could result in $8 billion in annual savings from a reduction of redundant testing alone.

HIEs should therefore be in a strong position to convince insurers that they generate value that accrues to them and that they therefore should invest in HIE development. However, our findings also lend credence to insurer concerns that misaligned provider incentives impede the realization of the full potential value from HIEs (Cross et al. 2016). They suggest that insurers would increase their benefit from investing in HIEs in markets with a greater penetration of capitation, and provide another motivation for pursuing more risk-based contracting with providers than is being promoted under recent federal payment reforms.[19] HIEs can also take steps to design the cost structure of stakeholder participation in ways that reflect these incentives. For example, HIEs could consider shared savings models in which insurers agree that a portion of avoided costs will go to HIEs. This approach could help convince insurers that they will benefit financially from supporting HIEs, while sustaining HIEs over the long term. New financial models should be considered as well, specifically, those that exploit the quasi-hierarchical structure in more advantageous ways. Scholars have noted that these coordination mechanisms allow for quicker access to knowledge and "know-how" (Powell 1987); this could become a monetizable asset that HIEs might consider selling to others. At the same time, the lagged benefits of HIE suggest that patience may be required on the part of insurers and providers before substantial gains from HIEs can be observed. Of course, it is also likely that increasing benefits over time will cap off at some point, particularly as HIEs fully mature and participation in the market becomes widespread. This suggests that early efforts will still need support from stakeholders (such as insurers) in the early period of HIE development, particularly since providers may be tempted to take a wait-and-see approach towards HIE adoption and only join after capabilities mature and benefits from HIE are more assured.

For policymakers, our findings underscore the motivation for pursuing HIEs and suggest they should continue to expand to all markets across the country. Given that federal funding for HIEs has recently been exhausted, now is a particularly critical time to assess new approaches that will ensure HIEs deliver on their potential for addressing high healthcare spending. Our findings suggest that continuing to push for greater expansion of risk-based payment, such as Accountable Care Organizations (ACO)[20] through Medicare, would increase the value generated by existing HIEs as well as potentially motivate new HIEs to emerge. There is reason to believe that, beyond the spending reductions that we demonstrate, HIEs may improve the quality of care by enabling better clinical decisions through improved information availability. Such benefits would further strengthen the motivation for ongoing support. Similarly, with payment reform and the rise in value-based payments, providers will need to more seriously consider strategies that improve quality and reduce spending. HIE is a compelling option, but one that has not had substantial evidence behind it. Our paper should help providers feel confident that HIE has the potential to reduce spending, particularly when provider incentives are aligned, as they will be under payment reform. However, as with any effort to adopt new technology, it will be critical for leading provider organizations to ensure that HIE is integrated into workflows in ways that ensure that newly available information is readily accessible at the point-of-care and is presented in ways that facilitate incorporation into clinical decision-making.

9. Conclusion

HIEs represent a timely and relevant technology effort in healthcare; they also highlight a more recent instantiation of IOIS to which the fundamental value proposition from information exchange is largely relevant. With information increasingly becoming a standalone economic asset and considerable developments in standardizing technology infrastructures with the potential to lower the cost of interorganizational technology efforts (e.g., cloud services), the role of information exchange efforts, TCE, associated governance models, and IOIS should be of theoretical and practical interest for some time to come. Against this backdrop, our findings identify key conditions that modify the value they create and can therefore be used to inform the design of IOIS efforts, as well as HIEs, in the future.

Endnotes

[1] Frictions can stem from transacting parties safeguarding their own interests at the expense of others, monitoring costs, communication inefficiencies, coordination costs, and costs associated with organizing information (Williamson 1981).

[2] Medicare covers those over 65 years of age, is the largest insurer in the United States covering 16% of the population, and accounts for 20% of national health expenditures. See http://tinyurl.com/medicare-stats1 and http://tinyurl.com/medicare-stats2.

[3] In fact, recent empirical work suggests that electronic health records could actually have some unintended effects on healthcare spending (Agha 2014, Li 2014, Ransbotham et al. 2013).

[4] This is based on $240 billion of qualified Medicare spending in 2015. These savings reflect early gains from HIEs because we observe HIEs during a period in which they were relatively new (prior work estimates total cost savings from exchange to be $80 billion annually in steady state, Walker et al. 2005).

[5] For example, the National Cyber-Forensics and Training Alliance (NCFTA) has developed an IOIS that does not involve any exchange of services between participants, but rather is used to share information between banks, retailers, and law enforcement for the purpose of coordinating the fight against cybercrime and fraud.

[6] Prior work has discussed a number of different hybrid governance structures including networks, quasi-markets, quasi-hierarchies, electronic hierarchies, etc. (Demil and Lecocq 2006; Exworthy et al. 1999; Powell 1987, 1990; Unertl et al. 2012). There are subtle differences, but in the interest of space, we do not exhaustively describe these organization forms. Instead, we focus on describing why a quasi-hierarchy fits the HIE context.

[7] The regional focus of HIEs is due to the significant variation in healthcare markets (even within a given state) and the focus of HIEs to enable clinical information to electronically follow patients between the settings in which they receive care, which also falls within a defined geographic region.

[8] Although we also identified 70 planning exchanges that did not reach operational status as of 2009, we focused on operational HIEs since spending reductions realized by Medicare would only occur after an HIE begins facilitating the exchange of health information among providers (data on planned exchanges was used in our robustness tests).

[9] See http://ahrf.hrsa.gov/.

[10] See http://tinyurl.com/MedAdvPlans.

[11] See http://tinyurl.com/kff-premiums and http://tinyurl.com/kff-medadv.

[12] Historical data was provided by the Dorenfest Institute.

[13] We do not include Medicare Advantage penetration as a control in our main estimation because two years of data was missing.

[14] For clarity, estimates on controls that were not predictive of Medicare spending were not included in our regression output.

[15] We do not include Medicare Advantage penetration as a control in our main estimation because data was missing for two years in our panel.

[16] These results are consistent when we include lagged measures of HIT adoption and more comprehensive measures of health IT adoption. This helps to alleviate concerns about unobserved levels of health IT integration driving these results.

[17] Seventy-four point one billion dollars is the estimate of total spending in the HRRs with active HIEs in 2009. This is derived by taking the product of average spending per beneficiary and the total number of Medicare beneficiaries in these HRRs. Assuming these HRRs experienced a 1.4% reduction in spending as a result of HIEs, we estimate that spending would have been $75.05 without HIEs in place (hence an approximate $1 billion dollar reduction as a result of HIEs).

[18] The national estimates of spending reduction are based on the 2015 Kaiser Family Foundation report on Medicare spending (http://tinyurl.com/kff-medspend) and take into account all of the spending categories included in our measure of Medicare spending. For example, we exclude Part D prescription drug spending since it is not part of our measure. Using a back-of-the-envelope calculation, we simply take a 1.4% reduction in the total spending of relevant categories to generate our estimate of reductions in spending from HIE if they had been nationally implemented in 2015.

[19] See the Affordable Care Act and the more recent Medicare Access and CHIP Reauthorization Act.

[20] The ACO concept is evolving, but generally, an ACO can be defined as a set of health care providers, including primary care physicians,

specialists, and hospitals, that work together collaboratively and accept collective accountability for the cost and quality of care delivered to a population of patients. See http://tinyurl.com/DefineACO.

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