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The Impact of Vertical Integration on Physician Behavior and Healthcare Delivery: Evidence from Gastroenterology Practices

Lina D. Song[1], Soroush Saghafian[2],
Joseph P. Newhouse[2,3], Mary Beth Landrum[3], John Hsu[4]

[1] PhD Program in Health Policy, Harvard University, Cambridge, MA 02138
[2] Harvard Kennedy School, Harvard University, Cambridge, MA 02138
[3] Harvard Medical School, Boston, MA 02115
[4] Massachusetts General Hospital, Boston, MA 02114

The U.S. healthcare system is undergoing a period of substantial changes, with hospitals purchasing many physician practices ("vertical integration"). In theory, this vertical integration could improve quality by promoting care coordination, but could also worsen it by impacting the care delivery patterns. The evidence quantifying these effects is limited, because of the lack of understanding of how physicians' behaviors alter in response to the changes in financial ownership and incentive structures of the integrated organizations. We study the impact of vertical integration by examining Medicare patients treated by gastroenterologists, a specialty with large outpatient volume, and a recent increase in vertical integration. Using a causal model and patient-level national panel data that includes 3.6 million patient visits across 5,488 physicians between 2008-2015, we examine changes in various measures of care delivery, including quality, operational efficiency, and spending. We find that physicians reduce provisions of recommended care processes (e.g., anesthesia with deep sedation) after they vertically integrate, and such changes result in a substantial increase in patients' post-procedure complications. We further provide evidence that the financial incentive structure of the integrated practices is the reason for the changes in physician behavior, because it discourages the integrated practices to allocate expensive resources to relatively unprofitable procedures. We also find that although integration improves operational efficiency (measured by physicians' throughput), it negatively affects quality while increasing the overall spending. Our cost-effectiveness analyses indicate that if increasing financial incentives can alter physicians' behavior, paying up to three times as much as the current price for deep sedation can be cost-effective. Put together, our results indicate that policies that promote integration should carefully align the incentives of integrated practices to prevent unintended consequences (e.g., lower quality and higher spending) while promoting higher levels of operational efficiency.

Key words: Vertical Integration; Healthcare Operations Management; Healthcare Quality; Provider Payment
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1. Introduction

The U.S. health care system is undergoing a period of substantial consolidation between physicians and hospitals, with hospitals purchasing many physician practices or directly employing physicians (Kocher and Sahni 2011, Burns et al. 2014, Alpert et al. 2017, Scott et al. 2017, Baker et al. 2018). The number of physicians who have "vertically integrated" (e.g., consolidated) with hospitals

has doubled in the past decade, and the trend is expected to continue (Kocher and Sahni 2011, Neprash et al. 2015, Scott et al. 2017, Nikpay et al. 2018). In theory, there are potential benefits of vertical integration such as greater efficiency through achieving economies of scale and better quality through achieving care coordination and information sharing (Kocher and Sahni 2011, Burns et al. 2014, Carlin et al. 2015, Baker et al. 2018, Baicker and Levy 2013, Lammers 2013). However, there are also concerns around its anticompetitive effect, which could increase the price and spending and lower quality (Neprash et al. 2015, Capps et al. 2018, Baker et al. 2014). A growing number of studies have examined the impact of integration on care delivery, but the evidence quantifying these effects on quality is still mixed (Post et al. 2018, Scott et al. 2017, Carlin et al. 2015, Lammers 2013). In particular, a key question that remains unanswered is whether vertical integration promotes a fundamental change in the way physicians operate and how such changes impact various dimensions of care delivery.

In this paper, we generate insights into this question by examining how hospital-physician integration affects quality, efficiency, and spending. We focus on the integration between hospitals and physician outpatient practices, where despite a clear change in the financial ownership of the organization, other factors that may affect the care delivery (e.g., physicians, patients, and geographic location) typically remain the same. This enables us to tease out the behavioral responses of the physicians from other contemporaneous changes. We find that when independent physicians integrate with a hospital, they simultaneously reduce recommended care processes (e.g., using deep sedation) and increase their operational efficiency (measured by throughput). The reduction in the process quality, in turn, adversely affects some key dimensions of patient outcomes. We further provide evidence that such behavioral changes are due to the changes in financial incentives of integrated physicians that limit the provision of value-adding care steps after integration. In addition to negative effects on care quality, integration results in an increase in per physician spending. Overall, our results suggest that the changes in financial ownership, without appropriate changes in the incentive structure to motivate the physicians' care processes in a positive direction, can have negative impacts on the healthcare delivery system through an increase in both adverse patient outcomes and spending.

1.1. Policy Context and Settings

Our study setting is the fee-for-service (FFS) Medicare, national health insurance that covers the majority of the elderly U.S. population.[1] Under the FFS payment model, services are not bundled, and providers are paid for each service at the administratively set prices. Importantly,

[1] In particular, the FFS provider payment policy relevant to the vertical integration we study is Medicare's payment for outpatient services (outpatient prospective payment system, or OPPS).

Medicare reimburses the same procedures that occurred at different settings differently: in general, procedures occurred at hospital outpatient departments (HOPDs) are paid higher rates than those at physician offices or ambulatory surgery centers (ASCs) (e.g., Medicare reimburses $1,090 for the colonoscopies that occurred at HOPDs, whereas only $413 for those at physician offices.) Yet, FFS Medicare patients can receive many of the outpatient procedures in different settings, and there is limited evidence that patients select themselves into different settings to justify such price differentials. Thus, these policies have been criticized for accelerating the trend of integration and contributing to the growth in Medicare outpatient spending by motivating hospitals to acquire physician-owned practice and convert the practice (usually in the same location) into an HOPD (Office of Inspector General 2014, Medicare Payment Advisory Commission (US) 2017, Forlines 2017, United States Government Accountability Office 2015).

Although there has been a legislative attempt to eliminate the fee differentials for non-grandfathered practices in January 2017 (Bipartisan Budget Act of 2015 (Section 603)), the more recent legislation has revised the site-neutral payment policy to expand exemptions (21st Century Cures Act). Clear policy recommendations have been difficult, mainly because of the lack of evidence on the impact of vertical integration on other dimensions of care delivery beyond expenditure (e.g., quality or efficiency). We contribute by establishing evidence on the impact of vertical integration on a variety of outcome measures (see Table 2) involving various aspects of care delivery. In addition, we make use of the evidence we establish to generate recommendations for policymakers, showing that if increasing financial incentives can alter physicians' behavior, paying up to three times as much as the current price for deep sedation can be cost-effective.

1.2. Challenges and Framework

There are several challenges in providing evidence on vertical integration. First, there is limited national-level data that can be used to provide generalizable evidence. For example, because many of the existing peer-reviewed studies focus on limited geographic areas, it makes it difficult to reconcile the different integration effects (Carlin et al. 2015, Wagner 2016). To address this challenge, we (a) make use of a data set that covers 20% of all fee-for-service (FFS) Medicare patients between 2008-2015, which includes 3.6 million observations of patient visits provided by 5,488 physicians, and (b) combine it with multiple other data sources that allow us to examine a wide range of measures, including quality, efficiency, and expenditures (Table 1).

Second, because the majority of acquisitions occur at a small scale (Capps et al. 2017), vertical integration is not easily identifiable from the survey data. We take advantage of the Medicare payment rules and providers' billing patterns to infer the financial relationship between physicians

Table 1: Overview of Our Dataset

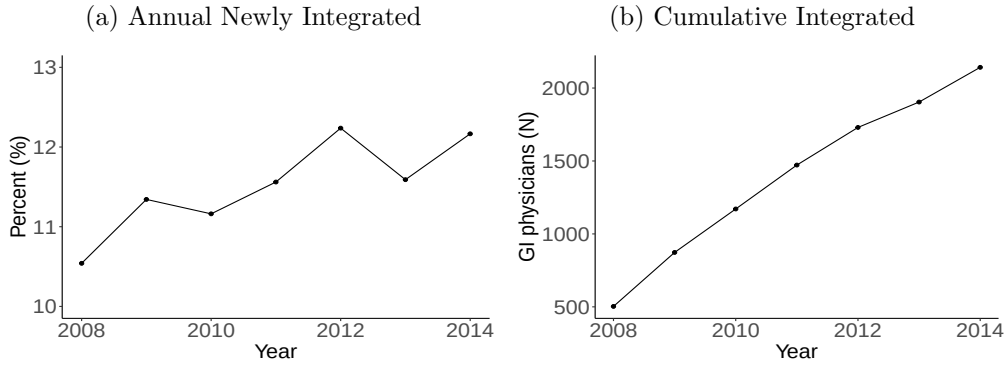
Name	Unit	Years
FFS Medicare Claims (Inpatient, Outpatient, Office)	Patient visit	2008-2015
Medicare Beneficiary Summary Files	Patient	2008-2015
CMS Physician and Other Supplier Data	Physician	2012-2015
Area Health Resource Files	County	2012, 2015
CMS State/County/Plan Enrollment Data	County	2008-2015

and hospitals. In this way, we are able to identify the integration status of individual physicians during each year in our study period (2008–2015).

Third, measuring the changes in outcomes before and after integration in a meaningful way is challenging. To address this challenge, we focus on a homogenous clinical area: Gastroenterology (GI). GI is one of the specialty areas that has experienced a rapid increase in vertical integration (Nikpay et al. 2018). Figure 1 depicts the trend of integration among gastroenterologists based on our data, and shows that integration has consistently increased between 2008-2014. In addition to a rapid increase in integration, focusing on GI has clear advantages because colonoscopy—a primary type of endoscopy for colorectal cancer (CRC) screening and diagnosis—has a set of well-validated process quality measures that are sensitive to the physicians' skills and are linked to important long-term patient outcomes such as interval cancer.

Fourth, there are various identification challenges that one needs to overcome to establish a causal effect of vertical integration. For example, physicians' decision to integrate is not exogenous; the physicians who are more likely to benefit from integration will do so, thus leaving the effect subject to selection bias. Specifically, the decision to integrate might depend on physicians' ability, strategy, and technology, which in turn can be correlated with their care delivery patterns. Thus, in order to show that vertical integration causes changes in care delivery, one needs to address the inherent differences between the physicians who decide to integrate with hospitals versus those who do not. We take advantage of our panel dataset and make use of a Difference-In-Differences (DID) fixed effects model that controls for unobserved differences between the comparison groups. To address the fact that the integration trend might be driven by other market factors such as technology, market demand, insurance structure, and socioeconomic factors, we link our panel data to other data sources and adjust for a set of relevant covariates. To gain further confidence, we also conduct multiple robustness checks on our assumptions. Finally, we employ econometric methods (e.g., mediation analysis) to identify the drivers of the changes we observe, which, in turn, allow us to provide clear policy recommendations.

Figure 1: Trend of GI Physician Integration Based on Our Data (2008-2014)



Note. From our analysis of Medicare FFS claims. The annual percent of newly integrated GI physicians was calculated as the total number of physicians who newly become integrated in the subsequent year out of the total number of independent physicians in a given year. Cumulative total integrated physicians in a given year were calculated as the sum of all GI physicians who integrated in the previous years and remained integrated in the given year.

1.3. Main Findings and Contributions

We find that vertical integration negatively affects the quality of care delivery. After physicians integrate, they reduce recommended care processes, especially the use of deep sedation (about 3.7 fewer patients receiving deep sedation per 100 patients).[2] Furthermore, the patients of integrated physicians experience a significant increase in major post-colonoscopy complications such as bleeding (3.8 per 1,000 colonoscopies) and minor complications such as GI or cardiac symptoms (3.3 per 1,000 colonoscopies). These effects occur even after adjusting for changes in patient composition and market characteristics. Through mediation analyses, we find that the reduction in the use of deep sedation, driven mainly by hospitals no longer allocating expensive anesthesiologists to relatively unprofitable colonoscopy, is the main mechanism through which the increase in adverse outcomes occurs. In addition to the changes in quality, we observe that integration increases physicians' throughout but yields higher spending per procedure. Notably, we find that integration causes physicians to spend about 132.6 more dollars per colonoscopy procedure. These changes ultimately result in an overall increase in per physician spending.

Taken together, our results indicate that, despite an increase in spending, vertical integration does not result in improvements in quality. Rather, the shift in the incentive structures of the organization as a result of integration can generate unintended negative consequences in both quality and spending. Our cost-effectiveness analyses reveal that if increasing financial incentives can alter physicians' behavior, paying up to three times the current price for deep sedation can be cost-effective. Overall, these findings show that policymakers should carefully align the incentives of

[2] Compared to other types of sedation, deep sedation requires more resources and coordination efforts since only anesthesiologists can administer it, whereas other types of sedation can be administrated by nurses. This describes why the impact on deep sedation is higher than other sedation types.

integrated practices to avoid negative consequences on quality and spending while taking advantage of the positive impacts of integration on operational efficiency.

2. Conceptual Framework

2.1. Background in GI Practices

Colonoscopy is a primary screening modality in GI practices for Colorectal Cancer (CRC) screening and diagnosis. During a colonoscopy, colonoscope—a long, flexible tube—is inserted into the rectum to examine the presence of polyps. Polyps can potentially develop into cancer and can be removed ("polypectomy") by the physician during colonoscopy. Thus, the key to a good outcome is how well the physician removes the polyps or adenomas (a benign tumor that may be precursor lesions to CRC). However, polyp removal is not always straightforward, and because the physician controls the entire process, the outcome is highly dependent on the quality of the preparation (e.g., bowel preparation, types of sedation) and the skill of the physician. There are common post-colonoscopy complications such as bleeding, infection, and in rare cases, perforation of the bowel. Currently, there is a wide unexplained variation in physician quality and colonoscopy outcomes (Corley et al. 2014).

2.2. Theories of Vertical Integration

Vertical integration in economics refers to the common ownership of two or more stages of production (or distribution) that are usually separate. Patients usually go through the vertical chain of healthcare, including primary care physicians, specialists, hospitals, and rehabilitation facilities. In this chain, specialists and hospitals are typically considered to be the upstream and the downstream entities, respectively. Economic theories suggest that there are roughly two types of motivation for vertical integration: efficiency-based and strategy-based (Baker et al. 2018, Post et al. 2018). Efficiency based theories propose that providers integrate primarily to eliminate inefficiencies in production. Strategy based theories propose that providers integrate to increase market power and/or employ the anticompetitive tactic to create barriers to entry (Gaynor 2014).

The efficiency based theory claims that if physicians and hospitals are under the same system, it can be easier to achieve smooth communication, reduction in duplicate services and waste, and goal setting/standardization of practices (Kocher and Sahni 2011, Burns et al. 2014, Baker et al. 2018, Baicker and Levy 2013, Lammers 2013). This will result in clinical integration, which management literature defines as the coordination of patient care services across the various functions, activities, and operating units of a delivery system (Gillies et al. 1993). Although it is believed that clinical integration is the gold standard for improving care quality, there is limited direct evidence that vertical integration will achieve clinical integration (Singer et al. 2018). On the other hand, the strategy-based theories suggest that integration for strategic purposes (e.g., vertical foreclosure)

will have a less direct impact on the outcomes, because the purpose of integration is to increase the market power and buy referrals. Such moves will not necessarily motivate organizations to achieve any clinical integration, or even worsen care, if increased market power results in lower motivation to compete on quality. These two theories generally predict the effect of integration in different directions. Because both positive and negative effects from the two theories are not inherently mutually exclusive, the pivotal question centers on the magnitude of changes.

Finally, we note that the changes in the financial structure of the organizations that integrate can affect physician behavior in different directions. First, for physicians, a positive income shock can increase the marginal utility of income, which may decrease their focus on quantity (number of patients or procedures performed) (McGuire 2000). In contrast, if quantity is reimbursed at the margin, the price increase[3] may incentivize them to increase their quantity. Second, when physician practices become integrated, physicians no longer face the direct financial risk, and compensation becomes primarily salary-based. Thus, integrated physicians may have less incentive for increasing their quantity which might have a negative impact on operational efficiency. At the same time, physicians at some organizations may still try to increase or maintain their quantity, especially if they are compensated by productivity or the volume of procedures. These make it difficult to predict the impact of integration on potential changes in physician behavior, and hence, various aspects of care delivery.

3. Literature

Our study is related to the stream of literature that examines the operational efficiency and the quality of service organizations. In particular, it is relevant to studies that examine the role of public policy (e.g., payment policy) and the provider market structures (e.g., mergers, exit, competition) in the operation of service organizations (Chen and Savva 2018, Song and Saghafian 2019). Within the context of vertical integration, most studies focus on their anticompetitive effect, i.e., how it affects spending and price (Neprash et al. 2015, Baker et al. 2014). Our study focuses on how integration affects the organizations' operational behaviors, quality, and spending.

Within the operations management literature that examines worker behavior in service organizations, our study is related to the empirical studies that examine how organizational settings affect the operational efficiency and quality of services (Tan and Netessine 2019, Wang and Zhou 2018, Meng et al. 2018, Staats et al. 2017). Studies have examined how specific characteristics of the organization affect worker behavior, such as the structural layout of the facility (Meng et al. 2018) or the monitoring program (Staats et al. 2017). Our study examines how the ownership of

[3] As noted earlier, the hospital-owned organizations receive greater payment per most of the same outpatient services from Medicare and other private insurance.

the organization affects the behavior of workers, and also identifies the specific changes in behavior that can impact performance.

Within the supply chain management literature, our work is related to studies that investigate how vertical integration can improve efficiency by reducing the double marginalization problems. The double marginalization problem has been studied extensively in the operations management literature, mostly through supply chain models (Heese 2007, Li et al. 2013). Fewer studies, however, have empirically evaluated how the behavioral changes within the integrating entities may influence the overall effect of vertical integration. Our study contributes by providing an empirical investigation in this regard.

Lastly, our study contributes to medical literature that explores the determinants of medical care quality (Song et al. 2010). Specifically, there are large unknown variations in the quality of GI practices, e.g., in CRC screening and diagnosis (Warren et al. 2009, Rabeneck et al. 2008). Through studying the differences between integrated and not integrated GI practices, our work contributes by shedding light on ways the variations in physician practices can be reduced, thus guiding the clinical and public health practitioners.

4. Data and Study Setting

4.1. Data

Table 1 provides an overview of all data sources we have used. Our main data source is a 20% sample of traditional FFS Medicare claims (Parts A and B) for inpatient, outpatient, and office visits between 2008 and 2015. The FFS Medicare claims provide detailed information on the healthcare services use of each patient visit, such as the procedures received through the Healthcare Common Procedure Coding System (HCPCS) codes, diagnosis through International Classification of Diseases (ICD-9) codes, and spending. We obtained each patient's sociodemographic information such as the age, sex, and 9-digit ZIP code from the Medicare Beneficiary Summary Files (BSF). We obtained each physician's information from the Physician and Other Supplier Public Use File from the Centers for Medicare & Medicaid Services (CMS), which provides information on the characteristics, utilization, and payment information on services and procedures provided to FFS Medicare beneficiaries by physicians (Centers for Medicare & Medicaid Services 2016). We incorporated the area level health care utilization, supply, and sociodemographic information from the Bureau of Health Professions' Area Resource Files (ARF), and the county level penetration rate of Medicare managed care plans from the CMS State/County/Plan Enrollment Data.

4.2. Measuring Vertical Integration

Existing studies have taken at least two different sets of approaches to measure vertical integration: survey-based and claims-based. Many studies have used the survey data such as the American

Hospital Association (AHA) Annual Survey or SK&A data of physician survey, which include questions on the hospitals or physicians' relationship with the other (Madison 2004, Cuellar and Gertler 2006, Scott et al. 2017, Baker et al. 2014, Wagner 2016, Capps et al. 2018, Koch et al. 2017). Although survey data can provide a direct source of information on integration, they may miss small integrations, be subject to misclassification, or fail to capture physician-level changes. Other studies have used claims-based approaches, which infers the providers' integration status from their billing patterns (Neprash et al. 2015, Konetzka et al. 2018, Desai and McWilliams 2018, Capps et al. 2018, Clough et al. 2017). These claims-based approaches are based on the rationale that (a) providers have a strong financial incentive to report the services that occurred at the hospital-owned practices due to the payment differential between the HOPDs and physician offices, and (b) only the practices that are 100% owned by a hospital can bill at a higher HOPD rate.

We make use of a claim-based approach and take advantage of our detailed data sources to directly measure integration. Specifically, for each physician j in year t, we first calculated the integration intensity as:

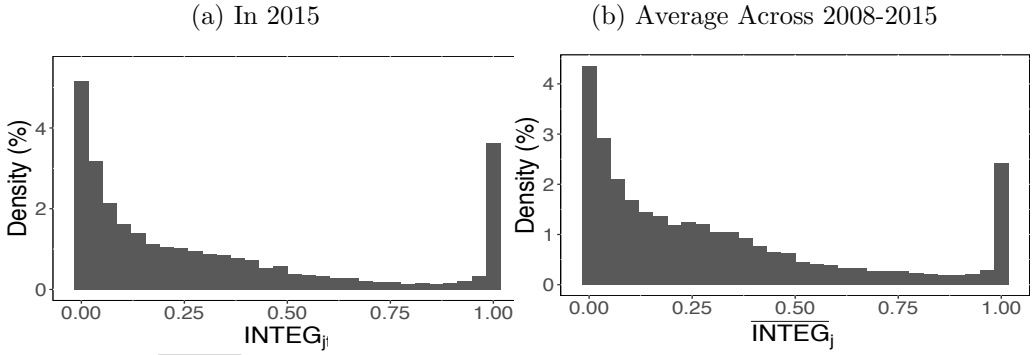
$$INTEG_{jt} = \frac{HOPD_{jt}}{HOPD_{jt} + OFFICE_{jt} + ASC_{jt}}, \tag{1}$$

where $HOPD_{jt}$, $OFFICE_{jt}$, and ASC_{jt} represent the total number of unique HOPD, office, and ASC-based claims, respectively.[4] $INTEG_{jt}$ takes a continuous value between 0 and 1, where $INTEG_{jt} = 1$ are the physicians who exclusively work at integrated practices ("fully integrated") and $INTEG_{jt} = 0$ are the physicians who exclusively work at independent practices ("independent"). Based on the distribution in Figure 2, the majority (79.5%) of physicians in our data set are within the range of $0 < INTEG_{jt} < 1$, which means they are neither independent nor fully integrated but practiced at both independent and hospital-owned practices in a given year ("partially integrated").

Previous studies that have examined other types of physicians, such as primary care physicians (PCPs) or cardiologists, have dichotomized the integration status into either independent or integrated (Neprash et al. 2015, Desai and McWilliams 2018, Clough et al. 2017). This dichotomization, however, disallows considering the fact that partially integrated physicians might have important differences in their practice patterns than either fully integrated or independent physicians (Allen and Kaushal 2018). While the acquisition of an independent GI practice results in their physicians changing their integration status from independent to partially integrated, the employment of physicians into a hospital-based HOPD (e.g., outpatient department on hospital's campus) results

[4] Unique claims are defined as the claims with the same beneficiary ID, service date, and the provider National Provider Identifier (NPI).

Figure 2: Distribution of $INTEG_{jt}$



Note. For each physician j, $\overline{INTEG}_j = \Sigma_t INTEG_{jt}/\Sigma_t T_t$ for all years t in the study period for which the physician submitted any claims.

in their integration status changing from independent or partially integrated to fully integrated. Unlike the integration driven by the acquisition of physician practice (which changes the financial relationship without changes in physical setting), the integration driven by employment will change both the financial and physical environment of the integrating physician. Since we are interested in identifying the impact of financial integration on physician behavior, we focus on the "partial integration" (when independent physicians become partially integrated), which consists of the majority of the integration in our sample. Thus, we eliminated the "full integration" in our main analysis, and later separately examine their effect. We also test the effect when we dichotomized the integration variable, which shows consistent findings (see Section 9). To implement our integration measure, we divided the integration types into three categories (fully integrated, partially integrated, and independent) as opposed to two (integrated or independent). We do so by making use of 0.1 and 0.9 as upper and lower thresholds on the integration intensity defined in (1).[5] For the rest of the analysis, we designate partial integration simply as integration.

4.3. Study Population and Comparison Groups

Our patient population is the FFS Medicare beneficiaries who received colonoscopies at any outpatient care settings during our study period, are aged between 65 and 85 at the time of the procedure and are entitled to Medicare due to age.[6] We also focused on the patients who have

[5] We set the thresholds at 0.1 and 0.9 instead of 0 and 1, because the majority of extremely low integration intensity values (e.g., $0 < INTEG_{jt} < 0.1$) in our data are due to the physicians in the transition stage (e.g., the year that s/he switches from independent to integrated). Indeed, independent physicians rarely become fully integrated within a given year (see Appendix A for more details). Nevertheless, in our robustness checks, we provide various sensitivity analyses on these thresholds and also re-run our analysis by considering a dichotomized version of integration (see Section 8.3 for more details).

[6] The guideline recommends against screening above age 85 (US Preventive Services Task Force 2008). Thus, we removed those above age 85 when they received colonoscopy from our main analysis, as are likely to be clinically different from the rest. We also limited the analysis to those aged 65 or above, since the Medicare beneficiaries under 65 are often sicker than a typical Medicare population (Cubanski et al. 2016). To ensure the observation of

received colonoscopy from GI physicians.[7] The claims for colonoscopy and related diagnoses were extracted using relevant ICD-9 and HCPCS codes (listed in the Online Appendix). For examining the effect of integration, the control group is the physicians who are either independent or partially integrated and did not change their integration status throughout the observation period. Our treatment group is the physicians who change their integration status from independent to partially integrated.

5. Variable Definitions and Descriptions

5.1. Outcome Variables

We divide our outcome variables into four categories: process-related quality, outcome-related quality, operational efficiency, and spending. All variables were measured primarily from the FFS Medicare inpatient, outpatient, and carrier claims. However, some physician efficiency measures (number of services, unique procedures, and patients) were obtained from the CMS Physician and Other Supplier Data. Because of the data limitation, these three variables were only available for years 2012-2015. All other variables were available for years 2008-2015. Below, we describe each of these separately. A summary of all our outcomes variables is presented in Table 2.

Process-Related Quality. We selected the process-related quality measures based on the endorsed quality indicators by professional societies (Rex et al. 2006). Among the suggested quality indicators, we selected those obtainable from the claims data that are (a) widely accepted, and (b) have the potential to be affected by the known variations among GI physicians' practices. For example, studies show that GI physicians with higher polypectomy rates tend to have better patient outcomes such as lower interval cancer (Warren et al. 2009, Kaminski et al. 2010). Thus, we measured the rate of polypectomy of physicians as a proxy for their process-related quality, after adjusting for various patient risk factors. We identified polypectomy rates from claims by the concurrent pathology bills (Warren et al. 2009). Incomplete colonoscopies can also be used as another proxy for measuring process quality, since they can result in missed lesions, a contributor

post-procedure adverse outcomes, we further restricted our analysis to those who have continuous enrollment in the FFS Medicare Parts A and B of one year before and 30 days after the colonoscopy date.

[7] Although the vast majority of the physicians who perform colonoscopies are GI physicians, a small number of other specialists such as colorectal surgeons and primary care physicians also perform them. Because the other specialists are likely to have different baseline skills, training, as well as patient characteristics (Baxter et al. 2012), we removed them from our analysis. Gastroenterologists, or GI physicians, were identified by the specialty code on claims (gastroenterology=10). We removed the colonoscopies performed by physicians with specialties such as "Colorectal surgery (=28)", "Internal medicine (=11)", or "family practice (=08)."

to the interval cancer (Cooper et al. 2012). We obtained incomplete colonoscopies directly from the HCPCS modifier codes 53, 73, or 74 on colonoscopy claims.[8]

Another key process measure of colonoscopy quality that we examined is the method of sedation used. Previously, the primary sedation method for screening colonoscopies had been through midazolam and an opioid. More recently, propofol sedation for outpatient colonoscopies has increasingly become popular (Khiani et al. 2012). Evidence shows that propofol sedation can provide fast onset of action, short duration of action, amnestic effects, faster recovery and discharge times and increased patient satisfaction (Chen and Rex 2004). However, there is a wide variation in the adoption of propofol for outpatient endoscopy. Thus, we measured the use of deep sedation (i.e., propofol as a method of anesthesia) as another indicator of procedure quality. We used the presence of anesthesiologist or nurse anesthetist to identify anesthesiology involvement (Cooper et al. 2012, Khiani et al. 2012).[9]

Outcome-Related Quality. We examined the three most common major complications—perforation, bleeding, and infection—that can result in serious health conditions, including death (Rex et al. 2006, Rabeneck et al. 2008). We also measured minor complications, defined as the presence of minor GI or cardiac symptoms discussed in the medical literature (Warren et al. 2009). For all complications, we identified these events using ICD-9 codes that are present either on or within seven days after colonoscopy. Finally, we measured the downstream health outcome, interval cancer, which is a type of CRC that occurs despite receiving a screening colonoscopy. We identified the interval cancer based on existing claims-based approaches (Quantin et al. 2012). The colonoscopy that was received six to 36 months before the diagnosis of cancer was defined as the one attributed to cancer. Conditional on genetic and clinical variations, interval CRC may occur due to an inadequate polypectomy or missed lesions. Thus, a higher interval cancer rate is a signal of poor physician quality after adjusting for the patient risk factors (Kaminski et al. 2010). The details of measurement and validation can be found in the Online Appendix.

Operational Efficiency. We used physicians' throughput and patients' waiting times as measures of operational efficiency. We calculated throughput as the total colonoscopy performed per physician per year, the total number of services provided per physician per year, the total number of unique procedures given per physician per year, and the total number of unique patients treated

[8] Modifier 53 indicates a discontinued procedure of physician services. Modifier 73 indicates a discontinued HOPD/ASC procedure prior to the administration of anesthesia. Modifier 74 indicates a discontinued HOPD/ASC procedure after the administration of anesthesia. Both modifiers 73 and 74 apply to facility charges.

[9] Because of the FDA regulation, another provider (i.e., an anesthesiologist or nurse anesthetist) must be present during the endoscopic procedure if propofol sedation is used during a colonoscopy. We followed the existing studies that relied on the presence of the CPT-4 code 00810, anesthesia assistance with endoscopic procedure distal to the duodenum, occurring on the same date as the colonoscopy of interest.

Table 2: Outcome Variables and Their Definitions

Category	Variable	Definition
Process-Related Quality	Polypectomy	Removal of at least one polyp during a colonoscopy.
	Incomplete colonoscopy	A colonoscopy that does not evaluate the colon past the distal third of the colon.
	Deep sedation	Use of propofol sedation during colonoscopy.
Outcome-Related Quality	Perforation	Incidence of a hole in the wall of part of the gastrointestinal tract.
	Gastrointestinal bleeding	Major and minor bleeding in the gastrointestinal tract.
	Infection	Incidence of bacterial infections after colonoscopy.
	Minor GI symptoms	Incidence of paralytic ileus, nausea, vomiting, dehydration, abdominal pain, diverticulitis, and enterocolitis.
	Cardiac symptoms	Incidence of arrhythmia, congestive heart failure, cardiac or respiratory arrest, syncope, hypotension, or shock.
	Interval cancer	Incidence of CRC 6 to 36 months after a negative colonoscopy.
Operational Efficiency	Time to complete colonoscopy	Time interval between incomplete colonoscopy to next colonoscopy.
	Time to treatment	Time interval between confirmatory colonoscopy to initiation of cancer treatment.
	Physician efficiency (throughput)	Total number of colonoscopies, services, unique procedures, or patients per GI physician per year.
Spending	Spending per procedure	Total spending occurred during the service event.
	Spending per physician	Total colonoscopy related spending occurred per physician per year.

Note. Major bleeding events include intracranial hemorrhage, hemoperitoneum, and inpatient or emergency department stays for gastrointestinal, hematuria, or not otherwise specified hemorrhage. Minor bleeding events included epistaxis, hemoptysis, vaginal hemorrhage, hemarthrosis and any outpatient claim for hematuria, gastrointestinal, and not otherwise specified hemorrhage.

per physician per year. Next, we measured two waiting times: time from incomplete colonoscopy to the next follow up colonoscopy, and time from positive colonoscopy to the initiation of surgery.[10] To address the physician attribution problem, where a patient receives initial and follow up colonoscopy from different physicians and the physician responsible for the outcome is unclear, we limited the analysis to the patients who received the two procedures from the same organization.

Spending. Although Medicare prices are administratively set, we examined the changes in spending per procedure to examine whether there is a change in the procedure mix (e.g., treatment intensity) that affects spending. For example, colonoscopy reimbursement rate varies by the type of specific procedures to remove polyps. Spending per procedure was defined as the total amount paid to the provider per colonoscopy (e.g., a unique date-physician-provider triplet), obtained from the beneficiary's claims. To better understand the overall spending and its policy implication, we also measured the annual per physician spending, which is a product of the changes in both per procedure spending and the per physician volume (see Table 2).

[10] For our DID analysis, we limited the sample to the patients who have either received the follow up colonoscopy or surgery within a year of the index colonoscopy. Because of the distributional shape of the time interval variables, we used a logged interval in our analyses.

5.2. Independent Variables

We divide the independent variables used in our models to three categories: patient characteristics, physician characteristics, and market characteristics. Below, we describe each of these separately. A summary of all our independent variables is presented in Table 3.

Patient Characteristics. In our models, we controlled for patient characteristics including demographic information such as age, gender, race/ethnicity, the reason for Medicare entitlement (i.e., whether or not a beneficiary is entitled to Medicare due to end-stage renal disease, or ESRD), and Medicare-Medicaid dual eligibility status (or "Duals"), a proxy used for low-income status. We accounted for the heterogeneity in patients' overall health risk by calculating each patient's Charlson Comorbidity Index (Elixhauser Comorbidity Index) (Elixhauser et al. 1998).[11] We also calculated the indicators for chronic conditions from the Chronic Conditions Data Warehouse algorithm (Chronic Condition Data Warehouse 2014), which uses diagnosis and procedure codes from the previous year to determine the 27 chronic conditions of the patient.

Physician Characteristics. We measured the physician characteristics such his/her geographical region of practice, the total number of affiliated practices measured as tax id number (TIN), and the indication of whether s/he is affiliated with a multispecialty clinic. For example, we counted the number of physician specialties affiliated with each organization and indicated the organization as a multispecialty practice if there were specialists other than gastroenterology or anesthesiology. Finally, we identified the ASC status of each physician's practice based on whether the practice submitted any ASC-based claims.

Market Characteristics. We controlled for the market concentration for a variety of reasons, including the fact that horizontal and vertical integration in the market can be correlated. To measure market concentration, we computed Herfindahl-Hirschman Indices (HHIs) for hospitals for each market (HRR). HHIs were calculated by summing the squared market shares of the organization.[12] We also included the Medicare Advantage (i.e., the managed care type of insurance for Medicare) penetration rates as a proxy for the insurance market structure. We controlled for the provider market supply by including the total number of GI physicians per person by county from AHRF. Finally, we included the county level sociodemographic characteristics such as the proportion of the population who are unemployed, in poverty, are under 65 of age from AHRF.

[11] The Elixhauser Comorbidity Index includes 30 diagnoses that can potentially increase the probability of adverse outcomes. We calculated the index directly from the patient's inpatient and outpatient claims history in the previous year and used the total number of chronic conditions in our main model (Elixhauser et al. 1998).

[12] According to the Department of Justice (DOJ) and Federal Trade Commission (FTC), the Horizontal Merger Guidelines, markets with HHIs below 1,500 are considered as unconcentrated, those with HHIs of 1,500'2,500 as moderately concentrated, and those with HHIs above 2,500 as highly concentrated (Shapiro 2010).

Table 3: Definition of Independent Variables and Data Sources

Variable	Description	Data source
Patient characteristics		
Age	Numeric, 64-86.	Medicare BSF
Gender	Binary, male or female.	Medicare BSF
Race	Factor, White, Black, Hispanic, Asian, or others.	Medicare BSF
Medicare entitlement	Binary, ESRD or not.	Medicare BSF
Medicaid eligibility	Binary, dual or non-dual.	Medicare BSF
Comorbidity	Numeric, from 0 (least severe) to 21 (most severe).	Medicare inpatient, outpatient claims
Chronic conditions	Numeric, from 0 to 27.	Medicare BSF
Location	Binary, rural or urban.	Medicare Cost Report, POS
Physician characteristics		
Number of affiliations	Numeric, greater than 0	Medicare inpatient, outpatient claims
Multispecialty	Binary, 0 or 1	Medicare inpatient, outpatient claims
ASC affiliation	Binary, 0 or 1	Medicare inpatient, outpatient claims
Market characteristics		
Herfindahl-Hirschman Index	Numeric, greater than 0	Medicare inpatient claims, Medicare Cost Report
Medicare Advantage penetration	Numeric, from 0 (no penetration) to 1 (full penetration).	State/County/Plan Enrollment Data
GI physician density	Numeric, from 0 (none) to 1 (all population) per person	AHRF
Unemployed	Numeric, from 0 (none) to 1 (all population) per county	AHRF
Poverty	Numeric, from 0 (none) to 1 (all population) per county	AHRF
Under age 65	Numeric, from 0 (none) to 1 (all population) per county	AHRF

5.3. Descriptive Statistics

Table 4 summarizes the cross-sectional patient characteristics and the outcome variables by their physicians' integration status in a given year. The cross-sectional measure of outcome rates was consistent with the estimates from existing literature (Rex et al. 2006). Overall, patients who receive colonoscopy from fully or partially integrated physicians are more likely to be Black race, Duals, have higher comorbidity index, and reside in rural areas (compared to patients receiving treatment from independent physicians). They are also more likely to have higher unadjusted adverse outcomes such as perforation, bleeding, infection, minor complications, and interval CRC. Notably, partially or fully integrated physicians provide deep sedation substantially less, equivalent to about 70.9% and 47.8% of the use of the independent physicians, respectively. Such differences between the integrated and independent physicians as well as their patients are further examined in our DID analysis.

6. Main Empirical Strategy

6.1. Overview

Our main empirical strategy is based on a DID analysis with physician, area, and year fixed effects. Under certain assumptions that we describe in the next section, the coefficient for the treatment variable in our model can provide a causal interpretation of how vertical integration affects care delivery. The unit of analysis in our model is a colonoscopy, and as noted before, various characteristics of patients, physicians, and markets are used as controls. The treatment

Table 4: Patient Characteristics and Outcome Variables by Integration Status

	Independent	Partial	Integrated
Observations (N)	1,094,303	1,373,297	126,448
Patients (N)	839,145	1,050,834	97,969
Demographic			
Age (mean)	73.18	73.30	73.07
Gender, Male (%)	45.25	44.87	45.65
Race, White (%)	87.29	87.71	84.50
Race, Black (%)	7.04	7.87	10.12
Race, Asian (%)	2.21	1.48	2.05
Race, Hispanic (%)	1.47	1.27	1.15
Duals (%)	8.35	9.07	11.60
Rural (%)	10.12	16.44	20.81
Comorbidity (mean)	1.53	1.59	1.63
Chronic conditions (%)	95.97	95.80	96.69
Process-Related Quality			
Polypectomy (%)	60.15	59.82	61.41
Incomplete colonoscopy (%)	1.66	1.62	2.11
Deep sedation (%)	57.81	41	27.62
Outcome-Related Quality			
Perforation (%)	0.12	0.16	0.20
Bleeding (%)	27.24	29.77	26.71
Infection (%)	0.18	0.25	0.35
Minor complications	11.60	13.48	12.15
Interval CRC (%)	0.24	0.25	0.29
Operational Efficiency			
Total colonoscopies per year (N/physician/year)	180.66	170.32	83.98
Total services per year (N/physician/year)	1,421.67	1,110.09	481.05
Total procedure types per year (N/physician/year)	38.71	42.17	32.87
Total patients seen year (N/physician/year)	454.69	458.96	261.86
Median time to followup (days)	24	28	23
Median time to surgery (days)	30.83	31.83	32.83
Spending			
Provider spending per colonoscopy (USD)	210.95	195.77	192.78
Facility spending per colonoscopy (USD)	388.23	570.52	645.96
Total spending per colonoscopy (USD)	262.81	544.64	742.90
Annual colonoscopy spending per physician (USD)	8,067.09	15,752.99	10,369.53

Note. Patients' integration status is assigned based on the physician they received colonoscopy from. Independent physicians have $0 < INTEG_{jt} < 0.1$, partial physicians have $0.1 < INTEG_{jt} < 0.9$, and integrated physicians have $0.9 < INTEG_{jt} < 1$. All characteristics differed at the significance level 0.001.

status/variable in our setting is based on the integration measure variable of the physician who performs the procedure. We allow multiple colonoscopies performed on the same patient to have different treatment status, if the patient received multiple colonoscopies from different physicians. The majority (73.0%) of patients, however, received only one colonoscopy during our study period. To perform our DID analysis, we made use of the following model:

$$Y_{ijt} = \alpha POST_{jt} + \beta \mathbf{X_{ijt}} + \gamma \mathbf{Z_{it}} + PHYSICIAN_j + MARKET_i + YEAR_t + \epsilon_{ijt}, \quad (2)$$

where Y represents the outcome variables such as process-related quality, outcome-related quality, operational efficiency, or spending, $POST$ is a binary variable that indicates that the obser-

vation is made post-integration for the treated group, $PHYSICIAN$ is the physician fixed effect, $MARKET$ is the market fixed effect, and $YEAR$ is the year fixed effect. $\mathbf{X}$ is the vector of patient characteristics, $\mathbf{Z}$ is the vector of market characteristics, and ϵ is an error term. Indices i, j, and t represent a patient, physician, and year, respectively. Bold notation is used to represent vectors.

6.2. Main Assumptions

The main assumptions of our identification strategy that are needed to provide a causal interpretation are: (a) parallel trends between the treatment and the control group, and (b) strict exogeneity. The parallel trend assumption imposes that, in the absence of treatment, the difference between the treatment and the control group is constant over time. There is no statistical test that can directly test this assumption, so we first examine the pre-integration trends for our outcomes. Our results depicted in Figure 1 of the Online Appendix confirms that there is a similar trend in outcomes before the physicians integrate. However, we note that for the outcomes that are relatively rare (e.g., incomplete colonoscopy, perforation, infection, and interval cancer), the parallel trend is less stable, likely because there is a fewer number of observations. However, for the outcomes that show significant changes based on our DID analysis (e.g., deep sedation, bleeding, and minor complications), the parallel trend is relatively stable. We also statistically test the differences in trend between the two groups by interacting each of the pre-integration years with our treatment variable. None of the interaction terms are significant, suggesting that there is no significant difference in time trends between the comparison groups before the integration.

The strict exogeneity condition assumes that the regressors are uncorrelated with the error terms. Such an assumption can be violated if, for example, the errors are correlated with unobserved and time-varying characteristics. Our rich set of covariates for patient and area characteristics, as well as the fixed effects at multiple levels, can address the heterogeneity between the comparison groups and year-specific shocks. However, there are still three sets of threats in our setting that can yield violations of the strict exogeneity assumption: patient selection to physicians, physician selection to integration status, and the changes in physician hidden behavior post-integration. Below, we discuss each of them separately.

Patient Selection to Physicians. Patients may select into different physicians in a way that is unobservable to us. For example, when physicians join a hospital or a large healthcare organization, their patients' perception of the quality of the service may change such that poorer or sicker patients select into integrated physicians. This can make it appear that integration worsens quality. Indeed, as noted before, we observe some baseline differences in patient characteristics in our data (Table 4). However, the concern for such selection is largely mitigated, because the selection has to be both time-varying and unobservable, which is not likely to be the case. This concern is further mitigated,

since we adjust for CRC specific risk, overall comorbidity, chronic conditions, and sociodemographic status. Also, relative to the choice of primary care physicians (PCPs), patients do not choose their specialists directly but are often referred by their PCPs (Barnett et al. 2012). Nevertheless, we later examine the changes in observed patient risk composition before and after the physicians integrate to further address this concern.

Physician Selection to Integration Status. We also note that physicians' decision to integrate is unlikely to be exogenous, and might be a result of their strategic behavior. For example, those who decide to integrate may prefer to collaborate with others more, which may also be correlated with their quality. It is also possible that the physicians' decisions to integrate are based on the pre-integration characteristics of their patient group. For example, physicians with a greater proportion of low-income or high-risk patients may decide to integrate to alleviate financial struggles. Finally, the market characteristics such as the degree of horizontal integration, the degree of managed care penetration, or the input costs may be correlated with both physicians' propensity to integrate and underlying patient health (Gaynor et al. 2013). These threats, again, only apply to an extent the differences are unobservable and time-varying, which will be mitigated by various controls we include using our rich multidimensional panel data. Nevertheless, we further examine the physician selection effect in multiple ways, including examining the effect of market conditions.

Physician Hidden Behavior Post-Integration. Integrated physicians may change their behavior in a way that confounds the integration effect. For example, physicians affiliated with an integrated organization are more likely to increase the coding intensity for reporting complications, which may affect the outcome-related quality measures we examine without impacting the true underlying quality. In particular, if physicians code for complications after colonoscopy more actively after they integrate (e.g., due to increased monitoring efforts), it may appear that the quality has worsened post-integration. However, we believe that this concern is mitigated for several reasons. First, major complications are less likely to be subject to variations in this coding behavior than minor complications, but our results show a stronger effect for major complications (e.g., bleeding). Second, we account for the fact that the patients can visit any of the inpatient, outpatient, or office settings for subsequent adverse outcomes, and are not limited to the same practice that they originally visited. This adverse outcome is, however, attributed to the original practice where they received a colonoscopy, not the practice they visit with the complications. Third, our examination of patient composition shows that the proportion of high-risk patients is fairly consistent, which weakens the argument that providers increase their coding intensity. Nevertheless, to gain further confidence, in our robustness checks, we test these assumptions in various ways (see Section 8).

7. Results and Discussions

7.1. Average Effect

Process-Related Quality. Figure 3 and Table 5 show the estimates of our DID coefficients. Full regression results are provided in the Online Appendix (Tables 1-4). Among the three process-related quality (polypectomy, incomplete colonoscopy, and deep sedation), polypectomy and incomplete colonoscopy do not change after integration. However, the physicians who integrate reduce the use of deep sedation by 7.7%, equivalent to about 3.7 fewer patients receiving deep sedation per 100 patients receiving colonoscopies.

Table 5: Regression Results

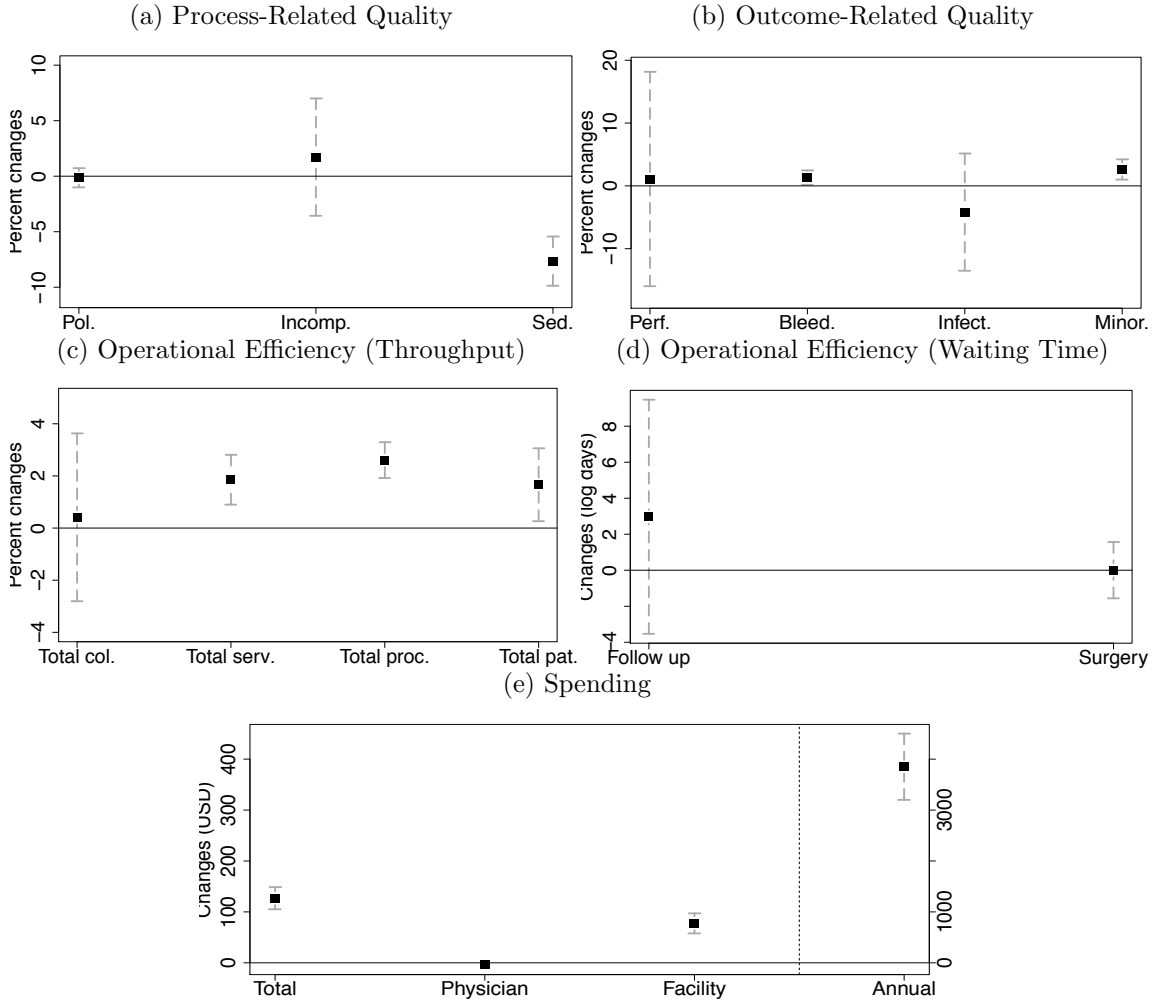
	Dependent variable: process and outcome-related quality							
	Pol.	Incomp.	Deep Sed.	Perf.	Bleed.	Infect.	Minor Comp.	Int. CRC
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
POST	−0.00084	0.00028	−0.037***	0.00002	0.0038*	−0.00009	0.0033*	−0.00014
	(0.0017)	(0.00044)	(0.0059)	(0.00012)	(0.0017)	(0.00010)	(0.0010)	(0.00026)
Obs.	2,442,582	2,442,582	2,442,582	2,442,582	2,442,582	2,442,582	2,442,582	1,551,886
R^2	0.097	0.032	0.529	0.013	0.127	0.022	0.102	0.019
Adj. R^2	0.092	0.026	0.527	0.007	0.122	0.016	0.098	0.012
Res. Std. Err.	0.467	0.125	0.344	0.037	0.424	0.047	0.316	0.056

	Dependent variable: operational efficiency and spending									
	Total Serv.	Total Col.	Total Proc.	Total Pat.	Follow. Time	Surg. Time	Total Spend.	Phy. Spend.	Fac. Spend.	Ann. Spend.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
POST	2.287*	5.146	3.241**	1.059**	0.078	0.0002	126.956***	−3.542***	77.477***	3,851.020***
	(20.460)	(0.852)	(0.142)	(3.260)	(0.087)	(0.027)	(11.105)	(0.536)	(10.043)	(331.907)
Obs.	24,025	66,908	34,398	33,337	16,124	40,639	2,442,582	2,442,582	976,456	67,362
R^2	0.924	0.871	0.922	0.947	0.641	0.291	0.359	0.263	0.365	0.816
Adj. R^2	0.871	0.845	0.889	0.924	0.504	0.069	0.355	0.259	0.357	0.778
Res. Std. Err.	721.685	52.363	5.739	78.940	1.186	1.148	287.040	60.216	292.382	5,690.967

Note. *p<0.05; **p<0.01; ***p<0.001. Pol. indicates polypectomy; Incomp. indicates incomplete colonoscopy. Deep Sed. indicates deep sedation; Perf. indicates perforation; Bleed. indicates bleeding. Infect. indicates infection; Minor Comp. indicates minor complication; Int. CRC indicates interval CRC; Serv. indicates services; Col. indicates colonoscopy; Proc. indicates procedures; Pat. indicates patients; Follow. indicates follow-up; Surg. indicates surgery; Spend. indicates spending; Phy. indicates physician; Fac. indicates facility; Ann. indicates annual; Obs. indicates observations; Adj. R^2 indicates adjusted R^2; Res. Std. Err. indicates residual standard error.

Outcome-Related Quality. Among the outcome-related quality (perforation, bleeding, infection, minor complications, and interval cancer), we observe that patients experience a significant increase in bleeding and minor complications after colonoscopy when their physicians integrate. Because both bleeding and minor complications are relatively common complications (e.g., the average 30-day incidence of bleeding and minor complications are 28.6% and 12.6%, respectively), such increases translate into about 3.8 and 3.3 additional bleeding and minor complications out of 1,000 colonoscopies, respectively.

Figure 3: Difference-in-Differences Estimates: Average Efect of Integration



Note. Pol. indicates polypectomy. Incomp. indicates incomplete colonoscopy. Sed. indicates deep sedation. Perf. indicates perforation. Bleed. indicates bleeding. Infect. indicates infection. Minor. indicates minor complications. Col. indicates colonoscopy. Serv. indicates services. Proc. indicates procedures. Each dot indicates the size of the DID coefficient. Each dot indicates the size of the DID coefficient. Grey lines depict the 95% confidence intervals around the coefficient of the DID variable. Standard errors are robust and clustered at the physician and the year levels.

Operational Efficiency. Overall, when GI physicians integrate, there are no significant changes in the waiting time, either to a follow-up colonoscopy or surgery after a positive colonoscopy (Figure 3). However, there are noticeable changes in the throughput measures: the GI physicians significantly increase three out of four measures of throughput (services, procedure types, and patients) after integration.

Spending. Our results show that for each colonoscopy visit, a physician's integration is associated with a $127.0 increase in total Medicare spending for a colonoscopy (Figure 3). The effect is driven by an increase in the facility fees after a physician integrated. The changes in spending are consistent with the price differential between physician offices and HOPDs, suggesting that integrated physicians do not alter their procedure mix (e.g., by increasing the provision of cheaper polypec-

tomy methods and reducing more expensive ones). We further verified that there are no significant changes in the proportion of specific procedure types (e.g., use of forceps vs. snare, hot vs. cold polypectomy) before and after a physician integrated (see Appendix Table 5), which suggests that the changes in the procedure mix did not drive up the spending. The annual colonoscopy Medicare spending increases by $\$3,851$ per year after physicians integrate, driven by both an increase in physician throughput and an increase in per procedure spending. Our results indicate that vertical integration increases spending not only through the administratively set price as existing evidence has shown, but also by changing the physician behavior to increase their throughput.

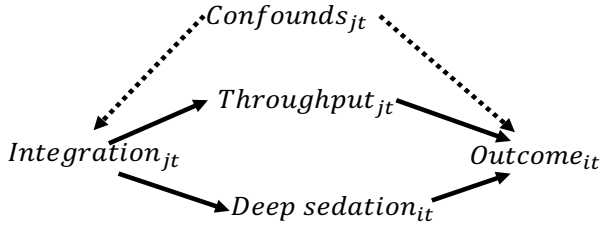
In summary, our main analysis shows that integration affects various dimensions of healthcare. There were significant changes in some aspects of the quality and operational efficiency: the use of deep sedation decreased, and the throughput substantially increased. Notably, the patients of integrated physicians experienced a direct impact on quality through an increase in some outcome-related quality measures such as bleeding and minor complication rates. How can we avoid these unintended negative consequences? To answer this question, we further examine the mechanisms that drive our results in the following sections.

7.2. Drivers of the Results

We further estimated the causal impact of vertical integration on outcome-related quality (bleeding and minor complications) that were present among the integrated physicians and the two potential mechanisms in the presence of unobserved confounding factors. Based on our main results, the increase in adverse outcomes among integrated physicians can be driven by at least two factors: changes in (a) the operational efficiency and (b) the process-related quality. Finally, there are other unmeasured changes accompanying integration. Figure 4 describes the pathways of integration effect as the directed acyclic graph (DAG).

Drivers of Increase in Adverse Outcomes. Insights from operations management literature suggest that changes in operational processes in the service system, such as the increases in service speed and/or the customers' waiting time, can negatively affect the quality of service (Chan et al. 2016, KC and Terwiesch 2009). Since the integrated physicians increase throughput while their patients experience worse outcomes, we hypothesize that the increases in the throughput might negatively affect patient outcomes. Second, the integrated physicians significantly reduce the recommended care process such as deep sedation. Medical literature indicates several benefits of deep sedation during colonoscopies such as the fast onset of action, short duration of action, amnestic effects, and faster recovery and discharge times, which in turn can improve quality (Chen and Rex 2004). A direct link between deep sedation rates and post-colonoscopy complications is not established, but the reduction in deep sedation among integrated providers may have resulted

Figure 4: Directed Acyclic Graph for the Causal Effect of Vertical Integration on Outcome-Related Quality



in increased 30-day complications by reducing some aspects of quality. Finally, the organizational changes as a result of integration unmeasured by our data may have driven physicians to reduce quality. To test these three possibilities, we made use of mediation analysis (see, e.g., Baron and Kenny (1986)): we first included deep sedation or physician's efficiency as an independent variable and re-examined the effect of integration on adverse outcomes. Specifically, we use the following model:

$$Y_{ijt} = \alpha POST_{jt} + \delta SEDATION_{ijt} + \beta \mathbf{X_{ijt}} + \gamma \mathbf{Z_{it}} + PHYSICIAN_j + MARKET_i + YEAR_t + \epsilon_{ijt}, \tag{3}$$

where $SEDATION_{ijt}$ is the binary variable for whether deep sedation was accompanied, and all variables are as previously defined. For examining the role of efficiency, we use the following model:

$$Y_{ijt} = \alpha POST_{jt} + \delta THRU_{jt} + \beta \mathbf{X_{ijt}} + \gamma \mathbf{Z_{it}} + PHYSICIAN_j + MARKET_i + YEAR_t + \epsilon_{ijt}, \tag{4}$$

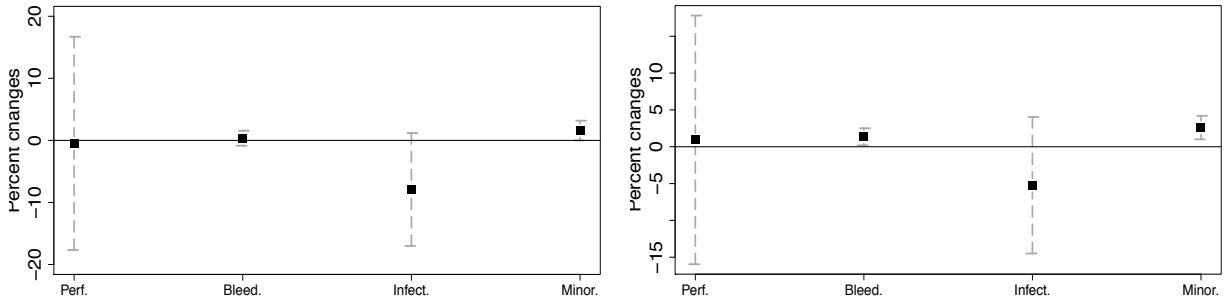
where $THRU_{jt}$ is the colonoscopy throughput per year for physician j in year t.

Our results presented in Figure 5 (and Table 6 of the Online Appendix) show that the effect of integration on adverse outcomes is either significantly reduced in magnitude or is no longer statistically significant after adjusting for deep sedation during the procedure, whereas the effect is consistent after adjusting for physicians' throughput. At the same time, the coefficient for deep sedation is significant and negative, indicating that providing deep sedation is associated with a reduction in adverse outcomes. Such results suggest that the reduction in the use of deep sedation after integration explains an increase in some of the adverse patient health outcomes. Finally, we verify that the changes in deep sedation use and throughput are not correlated after adjusting for other changes, i.e., physicians do not reduce deep sedation use in order to increase throughput or vice versa.

Drivers of Reduction in Deep Sedation. Given that the reduction in the deep sedation use among integrated physicians results in adverse patient outcomes, we next take a closer look at the potential drivers of the changes in deep sedation use after integration. Compared to other types of

Figure 5: Difference-in-Differences Estimates: Mediation Analyses

(a) Integration Adjusting for Deep Sedation (b) Integration Adjusting for Physician Efficiency



Note. Minor comp. indicates minor complications. All effects are scaled as changes in percentages. Each dot indicates the size of the DID coefficient. Grey lines depict the 95% confidence intervals around the coefficient of the DID variable. Standard errors are robust and clustered at the physician and the year levels.

sedation, deep sedation requires more resources and coordination efforts because only anesthesiologists can administer it, whereas other types of sedation can be administrated by nurses. Indeed, anecdotal evidence suggests the related scheduling and administrative processes for accessing anesthesiologists for colonoscopies are challenging because they usually have to compete with other procedures for their availability. Thus, the provision of deep sedation is more sensitive to the anesthesiologist's availability that an organization faces. There are two potential ways that integrated GI physicians face anesthesiologist supply constraints: (1) Constraints in the external margin (e.g., the fewer total number of available anesthesiologists) and (2) changes in the internal margin (e.g., fewer provision of deep sedation for colonoscopy per anesthesiologist). For the first case, an example would be when an integrated practice reduces the number of hired anesthesiologist or changes the intensity of employment. For the second case, an example would be when an acquired practice shifts anesthesiologist volume to procedures other than colonoscopies.

To examine the first pathway, we tested whether an integrated GI physician experiences a reduction in the total number of anesthesiologists that they potentially work with. For each GI physician, we measured the total number of the available anesthesiologist as the number of a unique anesthesiologist who has ever worked with a GI physician in a given year.[13] A typical GI physician worked with 6.6 anesthesiologists per year. We next used a DID model similar to our main model and used the total number of anesthesiologists an integrated GI physician worked with per year as an outcome variable to identify whether the change in integration status is associated with the outcome variable. Instead of a reduction in the number of affiliated anesthesiologists, we observe a slight increase among integrated physicians (DID coefficient: 0.81, SD: 0.12, p-value: < 0.001), which suggests that the first pathway is unlikely to drive the reduction in deep sedation use. To

[13] A GI physician and an anesthesiologist were considered to have worked together if they treat the same patient on the same date.

examine the second pathway, we measured the changes in the average number of deep sedation exclusively for colonoscopy performed by an integrated versus an independent anesthesiologist. We used a physician level DID analysis where the outcome is the total number of deep sedation for colonoscopy per anesthesiologist per year, adjusting for the anesthesiologist and year fixed effects. After an anesthesiologist integrates, s/he provides deep sedation for 2.79 (SD: 0.22, p-value: < 0.001) fewer colonoscopies per year (see Online Appendix Table 7 and 8 for more details). Our results suggest that while integrated practices do not necessarily reduce the number of the affiliated anesthesiologists, they shift their volume to services other than colonoscopies.

We note that the current payment structure for colonoscopies and deep sedation is consistent with the direction of changes in deep sedation use after integration: the average payment for deep sedation per GI procedure via anesthesiologist involvement in HOPDs for FFS Medicare patients is low, only \$157.3 in 2012. Such reimbursement rate is similar for physician offices and hospitals. An independent practice that focuses on providing large volume colonoscopy may still make profits, despite a high fixed cost of hiring anesthesiologists and low per procedure revenue, by economies of scale (e.g., attracting more patients, making each procedure shorter, and also providing large volume). However, for integrated practices potentially jointly managed with other specialties or practices, if the supply of anesthesiologists is fixed and if there are other competing practices with greater revenue (e.g., orthopedics or pain management), the opportunity cost of providing deep sedation through anesthesiologist for the practice may be low and may make more sense to allocate anesthesiologist to other procedures. Thus, the organizations that are sensitive to such price differentials will allocate anesthesiologists to the services that generate greater revenue. Our results suggest that addressing the incentive structure can thus mitigate or prevent the adverse impact of vertical integration, which we discuss further in Section 10.

8. Heterogeneous Effects

8.1. Examination of Full Integration

In our main analysis, we focus on the integration among the physicians who become independent to partially integrated, the majority of integration format among GI physicians. Here, we separately examine the effect when partially integrated physicians become fully integrated by applying the same approach and model specification from our main analysis (our DID regression results are presented in the Online Appendix Table 9 and Figure 2). We find some noticeable differences in the integration effect among the fully integrated physicians. Unlike the partially integrated physicians in our main analysis who reduce the deep sedation use and increase some post-colonoscopy complications, fully integrated physicians do not reduce the use of deep sedation, nor their patients experience any increases in complications. Moreover, despite experiencing an increase of \$75.4

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In summary, our results confirm that the behaviors of the fully integrated GI physicians are likely driven by different motivations than the ones affecting the majority of integrated GI physicians. One potential reason is that a large proportion of full integration involves the physicians becoming hired into hospital-based outpatient practices. Such integration will likely involve a different payment scheme and the changes in the work environment. The compensation scheme for the physicians at the hospital acquired independent practices are more likely to be connected to the volume or the profitability of the practice than those who work at the HOPDs on the hospital campus. Such differences may have resulted in the partially integrated physicians being more influenced by the changes in the incentive structure of the practice.

9. Robustness Checks

To test the spread and validity of our results, we performed various robustness checks. As we describe next, these include testing for changes in patient risk composition, investigating physicians' behavior, changing the measure of integration, and examining confounders such as the market competition. Finally, we conducted other statistical tests such as Bonferroni correction to address the risk of having positive results by chance when we conduct multiple comparisons on different outcomes, and the inverse probability weighting to adjust for the baseline differences in physicians, especially the pre-integration characteristics. The specific methods and results of these tests are in the Online Appendix. Overall, our results give us confidence that our results are fairly robust and are not sensitive to our assumptions and model specifications.

9.1. Changes in Patient Risk Composition

One important assumption of our identification strategy is that the changes in the quality of physicians who alter their integration are not due to the changes in patient characteristics. Given that distance is one of the primary factors for patients' physician choice and the majority of physicians' physical locations do not change after integration, such concerns on patient selection before and after integration can be mitigated. Yet, it is possible that the changes in the ownership status of a physician can result in attracting a different set of patients as a result of changes in perceived or actual quality. By examining whether there were any changes in observable patient characteristics, we can estimate whether the unobservable changes may be a significant threat to our identification strategy. We first examined the changes in observed patient composition when GI physicians integrate. For each physician, we tested whether the composition of patients with certain characteristics (demographic, clinical) changed following integration using a physician-level DID model:

$$Y_{jt} = \alpha INTEG_{jt} + \beta \mathbf{X_{jt}} + \gamma \mathbf{Z_{jt}} + PHYSICIAN_j + YEAR_t + \epsilon_{jt}, \tag{5}$$

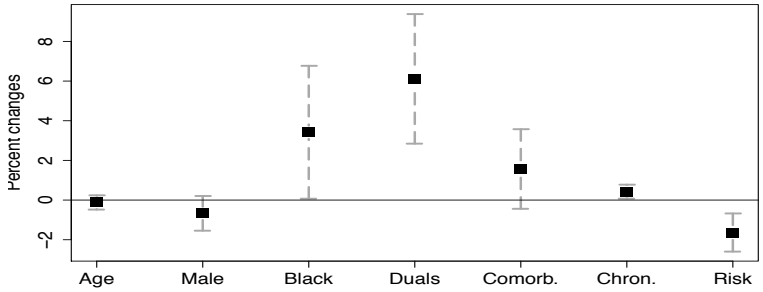
where Y is a measure of patient composition (e.g., out of all patients of physician j, number of patients with specific characteristics) for physician-year. Other variables are defined the same as our main model. Figure 6 shows that integration was associated with some demographic or clinical composition such that integrated physicians experienced a significant increase in the proportion of Dual patients and a marginal increase in chronic conditions. Importantly, we observe that integrated physicians experience a reduction in the proportion of patients with high risk for CRC.[14] If the unobserved risk also changed in the same direction as the observed risk after integration, the result suggests that the changes in patient composition would have biased our results in a direction that underestimates the adverse outcomes. Finally, we further included an indication of whether the patient is at high risk for CRC in our main analyses, and find that the effect was consistent when we included the CRC-specific risk variable, further providing evidence against the chance that an unobserved heterogeneity might be driving our results.

9.2. Physician Behavior

Coding and Gaming. Another important threat to our identification strategy is that physicians may change their coding behavior in a way that does not reflect the true changes in quality, depending on the administrative infrastructure of the newly integrated system. To test this assumption,

[14] Medicare considers an individual at high risk if he or she has one or more of the following: a close relative who has had colorectal cancer or an adenomatous polyp; a family history of familial adenomatous polyposis; a family history of hereditary nonpolyposis colorectal cancer; and a personal history of adenomatous polyps, colorectal cancer, or inflammatory bowel disease, including Crohn's disease, and ulcerative colitis.

Figure 6: Average Effect of Integration on Patient Composition, Scaled into Percent Changes



Note. All effects are scaled as changes in percentages. Each dot indicates the size of the DID coefficient. Grey lines depict the 95% confidence intervals around the coefficient of the DID variable. Standard errors are robust and clustered at the physician and the year levels.

we made use of the primary condition only to re-examine the integration effect on the two outcomes, bleeding and minor complications. Next, we examined limiting the definition of bleeding to major bleeding only, which are less likely to be subject to change as a result of changes in coding intensity. Our results in Table 6 suggest that there is no evidence that the potential changes in the coding intensity after integration would affect our main findings. Further, we note that there is no good reason for physicians to change their coding behavior for the purpose of gaming because the measures we detect changes (e.g., bleeding and minor complications) are not used for payment or direct quality measures tied to incentives during our observation period.

Retiring Physicians. We also tested if the shift to employment caused specific GI physicians to go part-time. For example, if the physicians who choose to integrate intend to do so for different reasons (e.g., on a path to retirement), this may affect both the efficiency and quality of their care differently from others. We first identified the GI physicians who are highly likely to retire as those who have submitted any claims for at least subsequent years but submitted no claims (including inpatient claims) for all subsequent years. We have identified a total of 1,131 GI physicians (6.9% of total GI physicians in our data) who are likely to be on a path to retirement during our observation period and re-ran the analyses among them. We observe that these physicians' changes in throughput and the use of deep sedation after integration are similar to the non-retiring physicians, and the main results are consistent when the retiring physicians and their patients are removed from the sample (see Table 6).

9.3. Measuring Integration

In our main analysis, we made use of specific threshold values (10% and 90% for partial and full integration, respectively) to define integration. Although these thresholds are supported both by our data and the literature on the practice patterns of GI physicians, we tested the sensitivity of our findings to these values. We made use of the following thresholds: 1% and 99%, 5% and 95%, and 15% and 85% for partial and full integration, respectively. Table 6 shows that varying the threshold

Table 6: Robustness Checks Results

	Outcomes	Deep sedation	Bleeding	Minor complications
Behavior	Major bleeding	NA‡	0.0038† (0.0017)	NA‡
	Exclude retiring physicians	-0.037^{***} (0.006)	0.004^{*} (0.002)	0.003^{*} (0.001)
Threshold	Cutoffs at 1%, 99%	-0.015^{*} (0.005)	0.004^{*} (0.002)	0.001 (0.002)
	Cutoffs at 5%, 95%	-0.041^{**} (0.008)	0.001† (0.002)	0.004^{*} (0.001)
	Cutoffs at 15%, 85%	-0.039^{***} (0.007)	0.003^{*} (0.001)	0.006^{*} (0.002)
	Binary integration variable	-0.039^{***} (0.0057)	0.0050^{*} (0.0016)	0.0041^{**} (0.0011)
Competition	Low	-0.031^{*} (0.009)	0.005^{*} (0.002)	0.004^{*} (0.001)
	High	-0.041^{***} (0.005)	0.004† (0.002)	0.003† (0.002)

Note. † indicates marginally significant at p-value < 0.10. ‡ indicates the results are not subject to change. We only present the results for the outcomes that had any significant changes in the main analyses. Standard errors in parentheses are robust and clustered at the physician and the year levels.

does not affect our main findings. We also used the binary integration variable (independent vs. integrated) instead to examine the integration effect. This is equivalent to considering all of the physicians who are either partially or fully integrated simply as "integrated". Defining integration in such way yielded the integration effect similar to that of partial integration in our main analysis, likely because there are greater physicians who are partially integrating.

9.4. Role of Competition

Integration can contribute to a reduction in the competition in the market. Given the fixed Medicare price, reduced competition might incentivize the practices to reduce their efforts on improving quality and/or efficiency. Thus, we examined whether the level of competition in the market plays a role in the integration effect by stratifying our sample into equal sizes of high (i.e., less than median HHI) versus low competition (i.e., greater than median HHI) areas. We do not observe a noticeable heterogeneity between these two groups (Table 6). This suggests that if unobserved changes in the market structure are consistent with the changes in market competition, it likely is not the major driver of our findings.

10. Summary and Limitations

We examine the impact of vertical integration on the quality of care (in terms of both process and patient outcomes), operational efficiency, and spending. Table 7 summarizes our findings, where favorable changes are indicated in blue, and unfavorable changes are indicated in red. Overall, our findings provide evidence that vertical integration adversely affects the quality while increasing the healthcare spending of the delivery system by altering physician behaviors. First, the reduction in some value-added care processes (e.g., deep sedation) leads to an increase in some adverse patient outcomes. We further show that this reduction in the value-added care process is, in turn, driven by the inherent financial incentive structure and subsequent constraints in anesthesiologist availability. Second, although there is a sign of an increase in some aspects of the operational efficiency, the

effect does not result in positive changes in quality. We also observe that spending increases post-integration as a result of a shift in volume to the integrated setting with greater financial incentives. Put together, our results suggest that vertical integration has negative consequences on various dimensions of healthcare delivery, and hence, requires careful consideration by policymakers.

Our study has a number of limitations. First, it focuses on a specific specialty (gastroenterology) and population (FFS Medicare). The findings may differ for other specialty practices that have different quality measures, provider roles, and characteristics of the disease. The younger population or the Medicare managed care population may also have different responses than the FFS population we studied. Second, there are various limitations from the nature of the data we used as well as our empirical strategy of DID. Although we discuss why the concerns for biases from both data and methods are mitigated (Section 6) and conduct various robustness checks (Section 8), it does not eliminate all of the threats to internal validity. For example, our physician efficiency measures are obtained from two different datasets, one of which is available for shorter observation periods of 2012-2015. Although both datasets present a consistent direction of integration effect, the data limitation should be highlighted. For measuring quality outcomes, there are various challenges with identifying variations in coding and billing patterns that one needs to consider. Similarly, measuring integration from our data is imperfect and subject to error. There are multiple forms of integration, and using claims data to infer them is inherently challenging. Having a rich dataset that can identify various nuances of integrated entities apart in the future would be helpful. Future research can also contribute by examining the impact of integration among different physician reimbursement structures, identifying the optimal size of incentives, and also by examining how it affects the quality from patients' perspectives. Given the importance of understanding how recent trends in vertical integration impact the health sector, we expect to see more research in this vein in the near future.

11. Policy Implications

Our results provide an overall negative picture of vertical integration, as it decreases some aspects of quality while increasing spending. Yet, we argue that such evidence does not necessarily indicate that the trend of vertical integration should be reversed. Vertical integration also brings in potentially positive effects, such as an increase in physicians' throughput. Our evidence also suggests that the negative impact of vertical integration is driven by the physicians' responses to the misaligned financial incentives, rather than other aspects of integration itself (e.g., increased coordination or volume). Thus, one immediate solution is to fix the current payment structure of integrated practices in a direction that promotes better quality. For example, integrated physicians could improve

Table 7: Summary of the Impact of Vertical Integration

	Outcomes	DID effect		Outcomes	DID effect
Process-related quality	Polypectomy	–	Operational efficiency	Time to follow-up	–
	Incomplete col.	–		Time to surgery	–
	Deep sedation	↓		Colonoscopies/year	–
Outcome-related quality	Perforation	–		Any services/year	↑
	Bleeding	↑		Procedure types/year	↑
	Infection	–		Patients/year	↑
	Minor comp.	↑	Spending	Total	↑
	Interval CRC	–		Physician	↓
				Facility	↑

their care delivery process and patient outcomes if the price for providing deep sedation among integrated practices is adjusted such that it is more consistent with the opportunity costs.

To assist policymakers, we performed counterfactual analyses to estimate the adverse outcomes averted under the scenario of the provision of deep sedation. If all GI physicians who did not provide deep sedation had done so, about 26 bleeding and 12 minor complications per 1,000 colonoscopies would have been averted. We further find that the effect size does not vary meaningfully by the physician or market characteristics (see Online Appendix Table 11). Using our estimate, we calculated the reasonable amount of incentive that can be provided to promote the provision of deep sedation through cost-effectiveness analyses. Suppose we can prevent the reduction of deep sedation use after integration through increasing the incentives. Assuming 0.1 quality-adjusted life years (QALYs) the maximum amount of utility loss associated with the post-colonoscopy adverse outcomes based on the literature (Graves et al. 2007) and knowing that spending up to $\$22,289$ for a unit of QALY is considered cost-effective in developed countries (Bertram et al. 2016), our QALY translates into the monetary value of 26.4*0.1 QALY gained per 1,000 patients $\times$ \$22,289 /QALY= \$588.4. Thus, paying up to \$588.4 additional incentives per colonoscopy to prevent the reduction of deep sedation use among integrating physicians can be cost-effective. This estimate critically depends on the assumption that providing financial incentives can alter physicians' or practices' behavior in a way that more anesthesiologists would be available to provide deep sedation for colonoscopies. Given that the incentive size is over three times the current payment rate for deep sedation, it is relatively large to alter the current physician behavior and still remain beneficial from a societal perspective.

More broadly, our results speak to the recent discussion around the innovative healthcare delivery and financing policies designed to encourage coordination among care providers. For example, Medicare Access and CHIP Reauthorization Act (MACRA) of 2015, which has revised the physician payment methods, creates a potential pathway for physicians to earn substantial bonuses for participating in alternative payment models favoring large organizations. Other provider payment

reforms such as bundled payment programs or the Federal 340B drug discount program all provide direct or indirect incentives for consolidations among providers in different production segment. Our results provide a cautionary message that when physicians financially integrate in response to these policies that use financial incentives, it would not guarantee that integrated practices will also achieve clinical integration. To ensure clinical integration, there should be additional measures to (a) monitor the post-integration physician behavior and quality and (b) align post-integration financial incentives. The CMS could require mandatory reporting of quality measures when a hospital acquires any physician practices, to ensure that the organization does not drastically alter its delivery of care. It can also implement payment policies that further promote the provision of high-value care process for the integrated practices to incentivize physicians.

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