

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

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Abstract. The U.S. healthcare system is undergoing a period of substantial change 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 a large outpatient volume and a recent increase in vertical integration. Using a causal model and large-scale patient-level national panel data that includes 2.6 million patient visits across 5,488 physicians, we examine changes in various measures of care delivery. We find that physicians significantly alter their care process (e.g., in using anesthesia with deep sedation) after they vertically integrate, and there is a substantial increase in patients’ postprocedure complications. We further provide evidence that the financial incentive structure of the integrated practices is the main reason for the changes in physician behavior because it discourages the integrated practices from allocating expensive resources to relatively unprofitable procedures. We also find that, although integration improves operational efficiency (e.g., measured by physicians’ throughput), it negatively affects quality and overall spending. Finally, to shed light on potential mechanisms through which policymakers can mitigate the negative consequences of vertical integration, we perform both mediation and cost-effectiveness analyses and highlight some useful policy levers.

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1. Introduction

The U.S. healthcare 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. 2013, Scott et al. 2017, Baker et al. 2018). The number of physicians who have “vertically integrated” (i.e., 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 economies of scale and better quality through achieving care coordination and information sharing (Kocher and Sahni 2011, Baicker and Levy 2013, Burns et al. 2013, Carlin et al. 2015, Baker et al. 2018). However,

there are also concerns around its anticompetitive effect, which could increase prices and spending and lower quality (Baker et al. 2014, Neprash et al. 2015, Capps et al. 2018). A growing number of studies examine the impact of integration on care delivery, but the evidence quantifying these effects on quality is still mixed (Carlin et al. 2015, Scott et al. 2017, Post et al. 2018).

Integration involves concurrent changes in multiple dimensions of care delivery, including structure, processes, and people (Singer et al. 2020). Structural integration includes the changes in physical, financial, or legal ties among the providers. Better structural integration can result in improvement in the care processes and collaboration among providers, which can result in better outcomes, but the relationships among these are difficult to disentangle. 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 one aspect of hospital–physician integration (e.g., changes in the behavioral responses of the physicians that might, in turn, be induced by forces such as a new financial incentive structure) affects the process, quality, efficiency, and spending. We focus on the integration between hospitals and physician outpatient practices, in which, 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 change their care processes (measured by a reduction in deep sedation use) and increase their operational efficiency (measured by throughput). In addition to the changes in the care process, integration adversely affects some patient outcomes. We further provide evidence that such 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 negatively affecting care quality, integration results in an increase in per-physician spending. Overall, our results suggest that changes in financial ownership without appropriate changes in the incentive structure to motivate the physicians' care processes in a positive direction can have unintended consequences on the healthcare delivery system through both reducing quality and increasing spending.

1.1. Policy Context and Setting

Our study setting is the fee-for-service (FFS) Medicare program, which covers the majority of the elderly U.S. population.¹ Under the FFS payment model, most services are not bundled, and providers are paid for each service at the administratively set prices. Importantly, Medicare reimburses the same procedure in different settings differently: in particular, a procedure that occurs in a hospital outpatient department (HOPD) is paid more than if it took place in a physician's office or an ambulatory surgery center (ASC). For example, Medicare reimburses \$917 on average for colonoscopies that occur in HOPDs in 2019 but only \$413 for those in physician offices. Yet FFS Medicare patients can receive many of the same outpatient procedures in different settings, and there is limited evidence that patients select into different settings to justify such price differentials. As a result, these policies have been criticized for accelerating integration and contributing to the growth in Medicare spending by motivating hospitals to acquire physician-owned practices and convert those practices (usually in the same location) into an HOPD (Office of Inspector

General 2014, U.S. Government Accountability Office 2015, Forlines 2017, Medicare Payment Advisory Commission (United States) 2017).

Although the Bipartisan Budget Act of 2015 (Section 603) attempted to eliminate the fee differentials for non-grandfathered practices as of January 2017, the more recent 21st Century Cures Act expanded exemptions further. Clear policy recommendations have been difficult mainly because evidence is lacking on how vertical integration affects dimensions of care delivery other than expenditure, especially quality and efficiency. We contribute by establishing evidence on the impact of vertical integration on a variety of outcome measures. From this evidence, we generate recommendations for policymakers, showing that, if financial incentives can alter physician behavior, paying an extra amount of money (by about half as much as the current price for deep sedation) to encourage the use of deep sedation and prevent changes in the process of care postintegration can be cost-effective.

1.2. Challenges and Framework

There are several challenges in providing evidence on the effects of vertical integration. First, many of the existing peer-reviewed studies focus on limited geographic areas, making it difficult to reconcile findings of different effects (Carlin et al. 2015, Wagner 2016). We, however, use a 20% random sample of all FFS Medicare patients between 2008 and 2015. These data include 2.6 million observations of patient visits provided by 5,488 physicians. We combine the Medicare data with multiple other data sources to examine quality, efficiency, and expenditure outcomes. An overview of our data sources is presented in Table 1.

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

Third, measuring 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 a specialty area with large outpatient procedure volumes 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 and 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 clinical quality measures that are sensitive to the physicians' skills and are linked to important long-term patient outcomes, such as interval cancer.

Table 1. Overview of Our Data Sources

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

Fourth, establishing causality is difficult because physicians' decisions to integrate are not exogenous; physicians who integrate are more likely to benefit from integration. Specifically, decisions to integrate presumptively 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. To do so, we take advantage of our panel data set and use a difference-in-differences (DID) fixed effects model that controls for stable unobserved differences between the comparison groups.

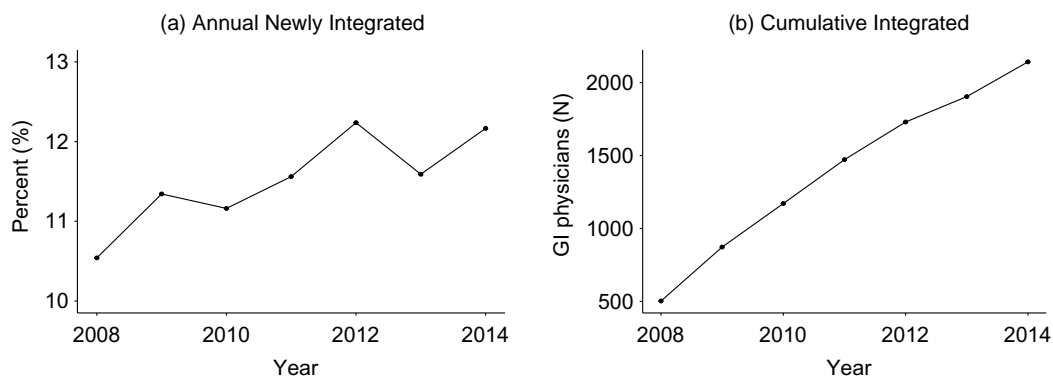
Fifth, integration might be driven by market factors other than reimbursement differences, such as technology, market demand, insurance structure, and socioeconomic factors, so we link our panel data to other data sources and adjust for a variety of relevant covariates. To gain further confidence, we also conduct multiple robustness checks on our assumptions. Finally, we employ mediation analysis to identify the drivers of the changes we observe, which, in turn, allows us to provide clear policy recommendations.

1.3. Main Findings and Contributions

We find that vertical integration negatively affects the quality of care. After physicians integrate, they alter their care delivery process. In particular, our results show

physicians that integrate reduce use of deep sedation, resulting in about 3.7 fewer patients receiving deep sedation per 100 patients.² Furthermore, patients of integrated physicians experience a significant increase in both major postcolonoscopy complications, such as bleeding (3.8 per 1,000 colonoscopies), and other complications, such as cardiac or nonserious GI symptoms (5.0 and 3.3 per 1,000 colonoscopies, respectively). These effects remain directionally the same 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 at least partially explains the increase in adverse outcomes. Moreover, such changes are driven mainly by hospitals no longer allocating expensive anesthesiologists to relatively unprofitable colonoscopy procedures. In addition, integration increases physicians' throughput and elevates reimbursement per procedure. Notably, we find that integration results in physicians being reimbursed about \$127 more per colonoscopy procedure, which is equivalent to an increase of 48% in mean per procedure spending of independent physicians.

Taken together, our results indicate that, despite an increase in spending and throughput, vertical integration does not improve the quality of care. 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 increasing the colonoscopy reimbursement

Figure 1. Trend of GI Physician Integration Based on Our Data (2008–2014)

Notes. From our analysis of Medicare FFS claims. The annual percentage 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 was calculated as the sum of all GI physicians who integrated in the previous years and remained integrated in the given year.

rate (by about 150%) to avoid a reduction in the use of deep sedation can be viewed as a cost-effective lever to prevent the unintended negative consequences of integration.

2. Background: Theories of Vertical Integration

Vertical integration refers to the common ownership of two or more stages of production (or distribution) that are initially separate. It is common in healthcare, in which primary care physicians refer patients to specialists, hospitals, and rehabilitation facilities. In the colonoscopy case, specialists and hospitals are considered to be the upstream and downstream entities, respectively. Economic theory suggests two motivations for vertical integration: efficiency- 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 to employ anticompetitive tactics to create barriers to entry (Gaynor 2014).

The efficiency-based theory claims that, if physicians and hospitals are under the same system, cost can be reduced from easier communication, reductions in duplicate services and waste, and goal setting/standardization of practices (Kocher and Sahni 2011, Baicker and Levy 2013, Burns et al. 2013, Baker et al. 2018). This results 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 many believe that clinical integration is the gold standard for improving care quality, there is limited direct evidence that vertical integration will actually achieve clinical integration (Singer et al. 2020).

On the other hand, the strategy-based theory suggests that integration for strategic purposes (vertical foreclosure) has a less direct impact on clinical outcomes because the principal purpose of integration is to increase an organization's market power and buy referrals. Such actions will not necessarily motivate the organization to achieve any clinical integration, and it could even worsen care if increased market power results in lower motivation to compete on quality. Whereas the efficiency-based theory predicts a positive effect, the strategy-based theory predicts no effect or a negative one. Because the two theories are not mutually exclusive, the pivotal question centers on their respective magnitudes.

Finally, we note that, if integration changes any fee that an individual physician receives, there are both income and substitution effects that work in opposite directions with respect to the supply of services, assuming the time per colonoscopy remains constant (McGuire 2000).

3. Literature

Our study is related to the stream of literature that examines service organizations' operational efficiency and quality of service. 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, Saghafian et al. 2022). Within the context of vertical integration, most studies focus on its anticompetitive effect, that is, how integration affects spending and price (Baker et al. 2014, Neprash et al. 2015). More recently, Vlachy et al. (2017) shows, using a game-theoretic framework, that the alignment between the hospital and physicians could have both a positive impact of reducing costs and a negative impact of decreasing quality. The impacts of better aligning hospital capabilities and patient needs and the policy levers that can yield improvements are also discussed in the literature (Saghafian and Hopp 2019, 2020). Our study focuses on providing empirical evidence of how integration affects the organizations' operational behaviors and quality as well as 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, both financial and nonfinancial, affect the operational efficiency and quality of services (Staats et al. 2017, Wang and Zhou 2018, Tan and Netessine 2019, Meng et al. 2021, Atkinson and Saghafian 2023). Such studies examine how specific characteristics of the organization affect worker behavior, such as the structural layout of the facility (Chan et al. 2019, Meng et al. 2021) or the monitoring program (Staats et al. 2017). A vast literature within operations management studies improving decisions made on routing patients (see, e.g., Saghafian et al. 2018, 2023) or treatments (see, e.g., Boloori et al. 2020). Other studies examine the role of innovative payment policies, such as the Hospital Readmissions Reduction Program (Chen and Savva 2018, Arifoğlu et al. 2020). Our study examines how the ownership of 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 problem. That problem is studied extensively in the operations management literature, mostly through supply chain models (Heese 2007, Li et al. 2013). Fewer studies, however, empirically evaluate how 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.

Finally, our study contributes to medical literature that explores the determinants of medical care quality

(see, e.g., Song et al. 2010). Specifically, there are large unknown variations in the quality of GI practices, for example, in CRC screening and diagnosis (Rabeneck et al. 2008, Warren et al. 2009). 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 clinical and public health practitioners.

4. Data and Study Setting

4.1. Data

As noted earlier, Table 1 provides an overview of our data sources. 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 each patient visit, including 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 age, sex, and nine-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 area-level healthcare utilization, supply, and sociodemographic information from the Bureau of Health Professions' area health resource files (AHRFs) 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 take at least two different approaches to measure vertical integration: survey-based and claims-based. Many survey-based studies use data such as the American Hospital Association annual survey or the SK&A physician survey, both of which include questions on the hospital's or the physician's relationship with the other (Madison 2004, Cuellar and Gertler 2006, Baker et al. 2014, Wagner 2016, Koch et al. 2017, Scott et al. 2017, Capps et al. 2018). 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.

The claims-based approaches infer the providers' integration status from their billing patterns (Neprash et al. 2015, Clough et al. 2017, Capps et al. 2018, Desai and McWilliams 2018, Konetzka et al. 2018). Their rationale is that (a) hospital-based providers have a strong financial incentive to report services that occurred at the hospital-

owned practices because of the payment differential between the HOPDs and physician offices, and (b) only the practices that are 100% owned by a hospital can bill at the higher HOPD rate.

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

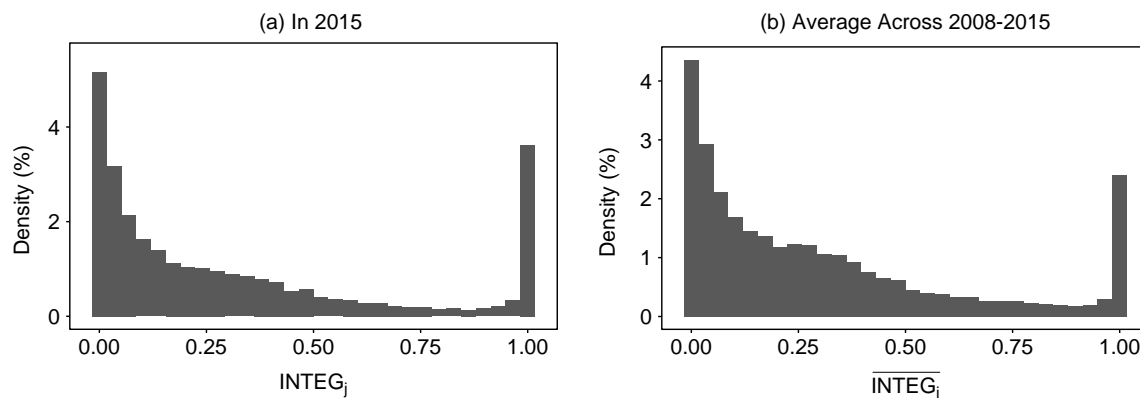
$$INTEG_{jt} = \frac{HOPD_{jt}}{HOPD_{jt} + OFFICE_{jt} + ASC_{jt}}, \quad (1)$$

where $HOPD_{jt}$, $OFFICE_{jt}$, and ASC_{jt} represent the total number of unique HOPD, office, and ASC-based claims, respectively.³ $INTEG_{jt}$ takes a continuous value between zero and one, for which $INTEG_{jt} = 1$ indicates physicians who exclusively work at integrated practices (fully integrated) and $INTEG_{jt} = 0$ indicates physicians who exclusively work at independent practices (independent). Based on the distribution of $INTEG_{jt}$ depicted 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 practice at both independent and hospital-owned practices in a given year (partially integrated).

In our main analyses, we define the three types of integration (independent, partial, and full), and make use of 0.1 and 0.9 as upper and lower thresholds of integration intensity in (1). 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 the physician switches from independent to integrated). In our robustness checks, we provide various sensitivity analyses on these thresholds.⁴

Previous studies of integration that examine other types of physicians, such as primary care physicians (PCPs) or cardiologists, have dichotomized integration status into either independent or integrated (Neprash et al. 2015, Clough et al. 2017, Desai and McWilliams 2018). Dichotomization, however, ignores potentially important differences between partially integrated physicians and both fully integrated or fully independent physicians (Allen and Kaushal 2018). If a hospital simply acquires an independent GI practice, the physicians may just change their integration status from independent to partially integrated. If the physicians are employed by the hospital, however, their integration status changes from independent or partially integrated to fully integrated. Unlike the acquisition scenario, which changes the financial relationship without changes in a physical setting, a change to employment will change the financial and may change the physical environment of the integrating physician. Because we are interested in identifying the impact of financial integration on physician behavior, we mainly focus on the partial integration (i.e.,

Figure 2. Distribution of $INTEG_{jt}$



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

when independent physicians become partially integrated), which consists of the majority of the integration cases in our sample. Thus, we separately examine the effect of full integration later (see Section 8.3).

4.3. Study Population and Comparison Groups

Our patient population is 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 because of age.⁵ We also focus on the patients who have received colonoscopy from GI physicians.⁶ The claims for colonoscopy and related diagnoses were extracted using relevant ICD-9 and HCPCS codes (listed in Online Table EC1).

5. Variable Definitions and Descriptions

5.1. Outcome Variables

We divide our outcome variables into four categories: process measures, postprocedure complications, operational efficiency, and spending. We measured most outcomes from the FFS Medicare inpatient, outpatient, and carrier claims although some physician efficiency measures (number of services, unique procedures, and patients) were obtained from the CMS physician and other supplier data. Because of data limitations, these latter three variables were only available for the years 2012–2015. All other variables were available for the years 2008–2015. We describe each of the four categories of our outcome variables separately. A summary of all our outcome variables is presented in Table 2.

5.1.1. Process Measures. We selected two process measures, polypectomy and incomplete colonoscopy, based on the criteria that they (a) are obtainable from the claims data, (b) are widely accepted measures in terms of process of care, and (c) have the potential to be affected by the known variations among GI physicians' practices.

Studies show that adenoma detection rate (ADR) (i.e., the proportion of patients with at least one colorectal adenoma detected during colonoscopy) is a well-validated metric for how a colonoscopy is delivered (Corley et al. 2014). However, because of the challenges with measuring it directly from claims data, we instead use polypectomy rate, given that polypectomy rate well correlates with ADR (Patel et al. 2013, Gohel et al. 2014). 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 changes in care processes that can reflect the changes in physician behavior. We identified polypectomy rates from claims by the concurrent pathology bills (Warren et al. 2009). Incomplete colonoscopy⁷ was selected based on the indicators endorsed by professional societies (Rex et al. 2006). Incomplete colonoscopies can be a proxy for measuring the process of care delivery, especially because they can result in missed lesions, a contributor to interval cancer (Cooper et al. 2012).

Another key process measure we examined is the method of sedation. Previously, the primary sedation method for screening colonoscopies had been through midazolam and an opioid. More recently, propofol sedation for outpatient colonoscopies has become popular (Khiani et al. 2012). Deep sedation has not formally been endorsed by professional societies as a quality measure, and hence, we only use it as a process measure to identify potential changes in how care is delivered.⁸ In particular, using deep sedation can improve patient experience through the fast onset of action, short duration of action, amnestic effects, faster recovery and discharge times, and increased patient satisfaction (Chen and Rex 2004). Yet whether the propofol sedation results in better post-procedure clinical outcomes, such as lower complication rate, is under debate, and there is a wide variation in the use of propofol for outpatient endoscopy (Singh et al.

Table 2. Outcome Variables and Their Definitions

Category	Variable	Definition
Process measures	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
Postprocedure complications	Deep sedation	Use of propofol sedation during colonoscopy
	Perforation	Incidence of a hole in the wall of part of the GI tract
	Gastrointestinal bleeding	Major and minor bleeding in the gastrointestinal tract
	Infection	Incidence of bacterial infections after colonoscopy
	Cardiovascular	Incidence of cardiovascular symptoms after colonoscopy
	Serious gastrointestinal	Incidence of serious GI symptoms after colonoscopy
Operational efficiency	Nonserious gastrointestinal	Incidence of nonserious GI symptoms after colonoscopy
	Interval cancer	Incidence of CRC 6 to 36 months after a negative colonoscopy
	Physician efficiency (throughput)	Total colonoscopies, services, unique procedures, or patients/physician/year
	Time to complete colonoscopy	Time interval between incomplete to next colonoscopy
Spending	Time to follow-up	Time interval between positive colonoscopy to follow-up colonoscopy
	Spending per procedure	Total, physician, or facility spending occurred during the service event
	Spending per physician	Total colonoscopy related spending occurred/physician/year

Notes. 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.

2008, Adams et al. 2017, Pace and Borgaonkar 2018). Thus, we also separately examine whether the changes in using deep sedation (as a process measure) affect post-procedure clinical outcomes, such as complication rates.

5.1.2. Postprocedure Complications. We next measured the quality of care using widely accepted procedural complications within a defined period after the surgery. These measures are listed in Table 2, and further details about them, codes we used to identify them (e.g., HCPCS and ICD-9 codes), and validations from the medical literature (see, e.g., Warren et al. 2009, Quantin et al. 2012, Robinson et al. 2015) and other sources can be found in Online Appendix EC1.

5.1.3. Operational Efficiency. We used physicians' throughput and patients' waiting times as measures of operational efficiency. We calculated throughput in various ways: the total colonoscopies performed per physician per year, the total number of services (i.e., a unique date–physician–provider triplet) provided per physician per year, the total number of unique procedures (i.e., a unique number of HCPCS codes submitted) given per physician per year, and the total number of unique patients treated per physician per year. We also measured two types of waiting times: time from incomplete colonoscopy to the next follow-up colonoscopy and time from positive colonoscopy to a follow-up colonoscopy.⁹ In some cases, a patient may receive initial and follow-up colonoscopies from physicians in different organizations so that the organization responsible for the outcome is unclear. To avoid ambiguity, we limited our analysis to patients who received the two procedures from the same organization.

5.1.4. Spending. Although Medicare unit prices are administratively set, we examined the changes in spending per procedure to determine if integration results in a change in the procedure mix (e.g., treatment intensity) that affects spending. For example, the colonoscopy reimbursement rate varies by the type of specific procedure used 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), which we obtained from the claims. To better understand the drivers of overall spending, we also measured annual per physician spending, which is a product of both per procedure spending and the per physician volume (see Table 2).

5.2. Independent Variables

Table 3 provides a summary of three types of independent variables we used in our models: patient, physician, and market characteristics.

5.2.1. Patient Characteristics. We controlled for patient age, gender, race/ethnicity, the reason for Medicare entitlement (i.e., whether a beneficiary is entitled to Medicare because of end-stage renal disease (ESRD)), and Medicare–Medicaid dual eligibility status (duals), a proxy for low-income status. We accounted for patients' health risks by calculating each patient's Elixhauser comorbidity index (Elixhauser et al. 1998).¹⁰ We also calculated indicators for chronic conditions from the Chronic Conditions Data Warehouse (2014) algorithm, which uses diagnosis and procedure codes from the previous year to determine which of 27 chronic conditions the patient may have.

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 nondual	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
Location of service	Factor, HOPD, Office, or ASC	Medicare 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

5.2.2. Physician Characteristics. We controlled for the physician’s region of practice, the total number of affiliated practices using the same tax identification number, and an indication of affiliation with a multispecialty clinic, which meant the practice had specialists other than gastroenterology or anesthesiology. We identified the ASC status of each physician’s practice based on whether the practice submitted any ASC-based claims. Finally, we included the location of each colonoscopy (e.g., HOPD, office, or ASC) as an independent variable in the analysis to determine whether the changes in outcomes for integrated practices are driven by the shift to more HOPD-based procedures or whether the changes spill over to procedures in other locations.

5.2.3. Market Characteristics. We controlled for market concentration because horizontal and vertical integration can be correlated. To measure market concentration, we computed Herfindahl–Hirschman indices (HHIs) for hospitals for each market. HHIs were calculated by summing the squared market shares of the organizations in the market. 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 the AHRF. Finally, we included county-level sociodemographic characteristics: the proportion of the population who are unemployed, in poverty, or are under 65 of age from the 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, averaged across 2008–2015. The cross-sectional measure of outcome rates is consistent with the estimates from the literature (Rex et al. 2006). Overall, patients who receive a colonoscopy from fully or partially integrated physicians are more likely to be Black, duals, have a higher comorbidity index, and reside in rural areas compared with patients receiving treatment from independent physicians. They are also more likely to have higher unadjusted postprocedure complications. Such differences between the integrated and independent physicians as well as their patients are further examined in our DID analysis to which we now turn.

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

Table 4. Patient Characteristics and Outcome Variables by Integration Status

	Independent	Partial	Integrated
Observations (<i>N</i>)	1,094,303	1,373,297	126,448
Patients (<i>N</i>)	839,145	1,050,834	97,969
Demographics			
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
≥1, %	95.97	95.80	96.69
Process measures			
Polypectomy, %	60.15	59.82	61.41
Incomplete colonoscopy, %	1.66	1.62	2.11
Deep sedation, %	57.81	41.00	27.62
Postprocedure complications			
Perforation, %	0.12	0.16	0.20
Bleeding, %	27.24	29.77	26.71
Infection, %	0.18	0.25	0.35
Cardiovascular, %	3.16	4.50	4.53
Serious gastrointestinal, %	5.90	5.99	4.77
Nonserious gastrointestinal, %	26.5	28.2	25.7
Interval CRC, %	0.24	0.25	0.29
Operational efficiency			
Total colonoscopies per year (<i>N</i> /physician/year)	180.66	170.32	83.98
Total services per year (<i>N</i> /physician/year)	1,421.67	1,110.09	481.05
Total procedure types per year (<i>N</i> /physician/year)	38.71	42.17	32.87
Total patients seen year (<i>N</i> /physician/year)	454.69	458.96	261.86
Median time after incomplete, days	27.70	27.27	26.45
Median time to follow-up, days	180.2	186.3	184.1
Spending			
Provider spending per colonoscopy, US\$	210.95	195.77	192.78
Facility spending per colonoscopy, US\$	388.23	570.52	645.96
Total spending per colonoscopy, US\$ ^a	262.81	544.64	742.90
Annual colonoscopy spending per physician, US\$	8,067.09	15,752.99	10,369.53

Notes. Patients' integration status is assigned based on the physician from whom they received colonoscopy. 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.

^aThe average total spending per colonoscopy is smaller than the sum of the average provider and facility spending because the physician does not receive the facility spending when the physician practices at a nonintegrated setting. Thus, for most independent and partially integrated physicians, the total spending is determined by the physician and not facility spending.

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, various characteristics of patients, physicians, and markets are used as controls. The treatment 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.¹¹ To perform our DID analysis, we made

use of the following model:

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

where Y represents outcome variables such as process-related quality, outcome-related quality, operational efficiency, or spending; $POST$ is a binary variable that indicates that the observation is postintegration for the treated group; $PHYSICIAN$ is the physician fixed effect; $MARKET$ is the market fixed effect; and $YEAR$ is the year fixed effect. X is the vector of patient characteristics, 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. Standard errors are clustered on physician group and year.

For some of the outcome variables that are measured at the physician level, such as throughput and spending, we use the following model:

$$Y_{jt} = \alpha POST_{jt} + \beta X_{jt} + \gamma Z_{jt} + PHYSICIAN_j + YEAR_t + \epsilon_{jt}, \quad (3)$$

where X is the vector of aggregated patient characteristics for each physician j in year t .

6.2. Main Assumptions

The main assumptions of our identification strategy that are needed to support a causal interpretation are (a) all effects other than integration affect physicians equally as tested by parallel trends in outcome variables between the treatment and control groups in the preintegration period and (b) strict exogeneity. Online Figure EC1 confirms that there are similar trends in outcomes before the physicians integrate, and hence, the parallel trend assumption is fairly satisfied. For relatively rare outcomes, such as incomplete colonoscopy, perforation, infection, and interval cancer, however, the parallel trend is less stable likely because of the small number of observations. However, for outcomes that show significant changes based on our DID analysis, such as deep sedation, bleeding, and other complications, the parallel trend is stable. We also statistically test the differences in trend between the two groups by interacting each of the preintegration years with our treatment variable (see Online Table EC2). None of the interaction terms is significant, suggesting no significant difference in time trends between the comparison groups prior to integration. We additionally test the parallel trend assumption using an event study specification (for two years preintegration and postintegration), which shows that the integration effects appear after the first year of integration and are consistent across the two years (the details can be found in the online appendix). Finally, estimated treatment effects in our setting do not vary based on treatment timing, so we did not allow for heterogeneity across units and related strategies (Sun and Shapiro 2022, Roth et al. 2023).

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, time-varying characteristics. Our rich set of covariates for patient and area characteristics (see, e.g., variables listed in Table 3) as well as the fixed effects at multiple levels, address the heterogeneity between the comparison groups and year-specific shocks. However, there are still three threats to the strict exogeneity assumption: patient selection of physicians, physician selection into integration status, and changes in physician hidden behavior postintegration.

6.2.1. Patient Selection to Physicians. Patients may select physicians in a nonrandom way that is unobservable to us. For example, when physicians join a hospital or a large healthcare organization, 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). Because the selection has to be both time-varying and unobservable, this does not seem to be a major threat. This concern is further mitigated because we adjust for overall comorbidity, chronic conditions, and sociodemographic status. Furthermore, many 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.

6.2.2. Physician Selection to Integration Status. As noted, physicians' decisions to integrate are unlikely to be exogenous and might result from strategic behavior. For example, those who decide to integrate may prefer to collaborate more with others, which may also be correlated with their quality. It is also possible that physicians' decisions to integrate are based on the preintegration 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). Because these threats only apply to the extent the differences are unobservable and time-varying, they should be mitigated by the various controls we include. We further examine the physician selection effect in multiple ways, including using matched physician samples and examining the effect of market conditions (see, e.g., Section 8).

6.2.3. Physician Hidden Behavior Postintegration. Integrated physicians may change their behavior in a way that confounds the integration effect. For example, physicians affiliated with an integrated organization may 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 because of increased monitoring efforts, it may appear that the quality has worsened postintegration. 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 patients' ability to 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 preintegration and postintegration, 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 Discussion

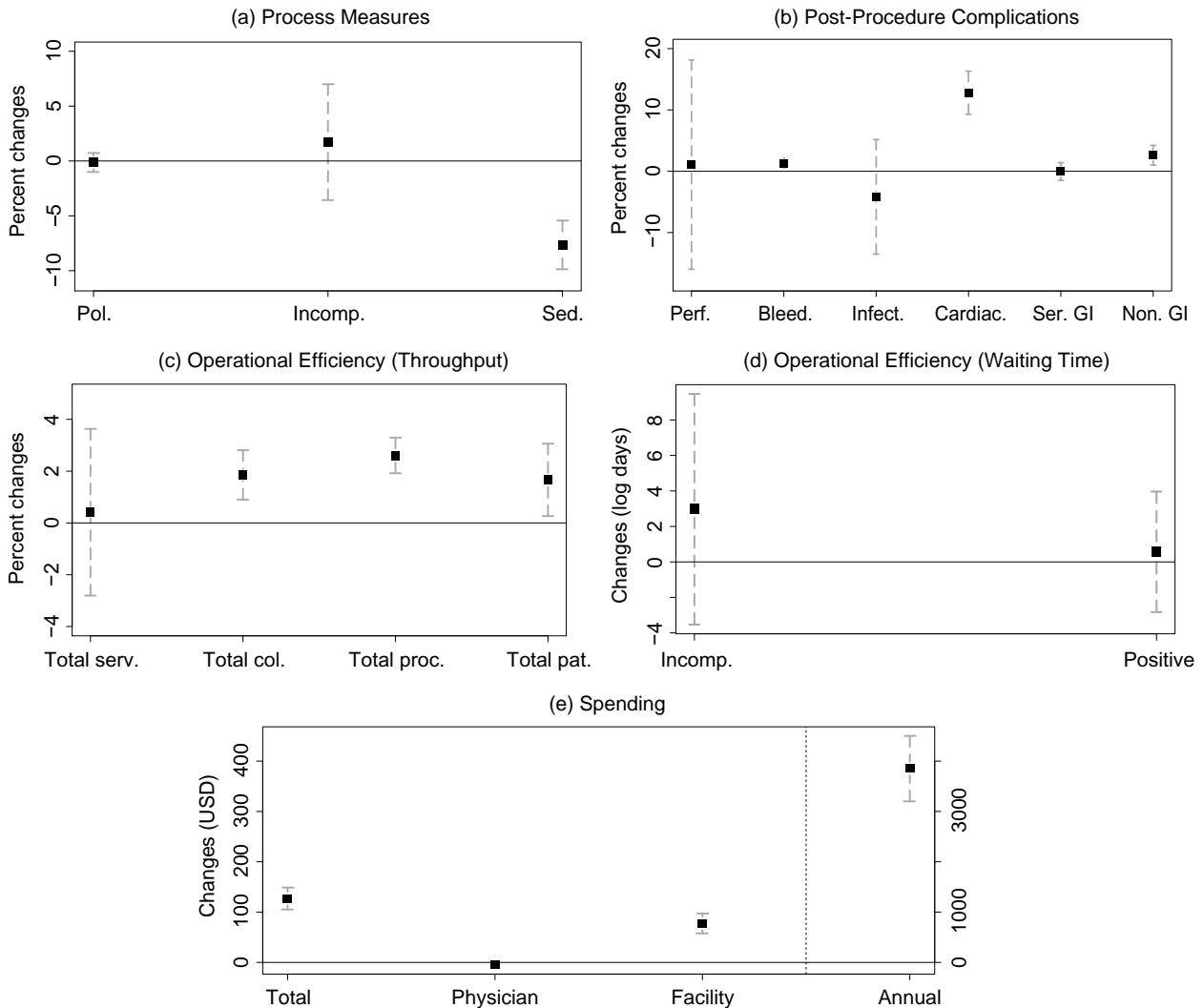
7.1. Average Effects of Integration

As noted earlier, in our main analysis, we focus on the impact of independent physicians becoming partially

integrated, which constitutes the majority of integration cases in our data. Thus, in what follows, we simply label this type of integration as "integration." In later sections, we expand our analyses to other types of integration and provide various robustness checks on our definitions of integration types (see Section 8.3).

7.1.1. Process Measures. Figure 3 and Table 5 show the estimates of our DID coefficients. Full regression results are provided in Online Tables EC3–EC7. Among the three process measures (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. This

Figure 3. DID Estimates: Average Effects of Integration



Notes. Bleed., bleeding; Cardiac., cardiovascular symptoms; Col., colonoscopy; Incomp., incomplete colonoscopy; Infect., infection; Non. GI, non-serious GI symptoms; Perf., perforation; Pol., polypectomy; Proc., indicates procedures; Sed., deep sedation; Ser. GI, serious GI symptoms; Serv., indicates services. 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 year levels.

Table 5. Regression Results

	Dependent variable: process measures and postprocedure complications									
	Pol. (1)	Incomp. (2)	Deep Sed. (3)	Perf. (4)	Bleed. (5)	Infect. (6)	Cardiac. (7)	Seri. GI (8)	Non. GI (9)	Int. CRC (10)
POST	-0.00084 (0.0017)	0.00028 (0.00044)	-0.037*** (0.0059)	0.00002 (0.00012)	0.0038** (0.0012)	-0.00009 (0.00010)	0.005*** (0.0007)	-0.0001 (0.0020)	0.0033* (0.0010)	-0.00014 (0.00026)
Observations	2,442,582	2,442,582	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	0.068	0.120	0.102	0.019
Adjusted R ²	0.092	0.026	0.527	0.007	0.122	0.016	0.068	0.116	0.098	0.012
Residual standard error	0.467	0.125	0.344	0.037	0.424	0.047	0.187	0.420	0.316	0.056

	Dependent variable: operational efficiency and spending									
	Total Serv. (1)	Total Col. (2)	Total Proc. (3)	Total Pat. (4)	Incomp. Time (5)	Follow. Time (6)	Total Spend. (7)	Phy. Spend. (8)	Fac. Spend. (9)	Ann. Spend. (10)
POST	5.146 (20.460)	3.241** (0.852)	1.059** (0.142)	7.596* (2.260)	0.152 (0.135)	0.078 (0.087)	127.0*** (11.1)	-3.5*** (0.54)	77.5*** (10.0)	3,851.0*** (331.9)
Observations	24,025	66,908	34,398	33,337	12,968	16,124	2,442,582	2,442,582	976,456	67,362
R ²	0.924	0.871	0.922	0.947	0.682	0.641	0.359	0.263	0.365	0.816
Adjusted R ²	0.871	0.845	0.889	0.924	0.548	0.504	0.355	0.259	0.357	0.778
Residual standard error	721.685	52.363	5.739	78.940	1.114	1.186	287.040	60.216	292.382	5,690.967

Notes. Bleed., bleeding; Cardiac., cardiovascular symptoms; Col., colonoscopy; Deep Sed., deep sedation; Fac., facility; Follow, follow-up; Incomp., incomplete colonoscopy; Infect., infection; Int. CRC, interval CRC; Non. GI, nonserious GI symptoms; Pat., patients; Perf., perforation; Pol., polypectomy; Proc., indicates procedures; Phy, physician; Sed., deep sedation; Seri. GI, serious GI symptoms; Serv., indicates services; Spend, spending. "Ann." indicates annual. Standard errors are robust and clustered at the physician and year levels.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

effect includes the adjustment for the location of service (HOPD, ASC, etc.).

7.1.2. Postprocedure Complications. Among various potential complications, patients experience a significant increase in bleeding, cardiac symptoms, and nonserious GI symptoms after colonoscopy when their physicians integrate. Because these complications are relatively common (e.g., the average 30-day incidence of bleeding, cardiac symptoms, and nonserious GI symptoms are 28.6%, 3.94%, and 26.8%, respectively), such increases translate into about 3.8, 5.0, and 3.3 additional bleeding, cardiac symptoms, and nonserious GI symptoms out of 1,000 colonoscopies, respectively.

Some of our outcome measures are compound outcomes that are potentially correlated with each other, and there is a risk of having positive results by chance when we conduct multiple comparisons on different outcomes. For example, perforation can result in increased bleeding. Hence, we correct for the potential correlation between different outcomes by conducting multiple testing adjustments for all of the 10 process- or outcome-related quality measures that are significant under the assumption of independent hypotheses. We used Bonferroni, the most conservative multiple comparison test (Benjamini and Hochberg 1995), and the family-wise error rates remain significant for three of the four outcomes that were significant under our main model (i.e., deep sedation, bleeding, and cardiac symptoms) and

nonserious GI symptoms remained marginally significant (see Online Table EC15).

7.1.3. Operational Efficiency. Overall, when GI physicians integrate, there are no significant changes in the waiting time variables we measure either to a follow-up colonoscopy after incomplete or positive colonoscopy (Figure 3). Because these two outcomes are limited to the patients who received two procedures from the same organization, we additionally examined the potential selection by comparing the follow-up rate by providers' integration status. Online Table EC17 shows that the follow-up rates do not differ significantly based on the integration status.

There are noticeable changes in the throughput measures: the GI physicians significantly increase three out of four measures of throughput (colonoscopy services, procedure types, and patients) after integration. Timely follow-up after incomplete or positive colonoscopy is an important indicator of quality (Winawer et al. 2006). Thus, the fact that follow-up interval does not improve despite the physicians increasing their throughput suggests that the increase in throughput is less likely to be an indication of improved care quality but a response to changes in financial incentives (e.g., greater payment for colonoscopies performed at integrated settings). We further examine the mechanisms behind the increase in throughput in Section 7.4.

7.1.4. Spending. Our results show that, for each colonoscopy visit, a physician's integration is associated with a \$127 increase in total Medicare spending for a colonoscopy (Figure 3). The effect is driven by an increase in the facility fees after a physician has integrated. The estimated change in spending is consistent with the price differential between physician offices and HOPDs, suggesting that integrated physicians do not alter their procedure mix (e.g., by reducing the provision of cheaper polypectomy methods and increasing more expensive ones). We further verified that there are no significant changes in the proportion of specific procedure types (e.g., single or multiple biopsies or specific types of polypectomy methods)¹² before and after a physician integrated, which suggests that any changes in the procedure mix did not drive up the spending (see Online Table EC8). Annual colonoscopy Medicare spending increases by \$3,851 per year after physicians integrate, driven by increases in both physician throughput and per-procedure spending. Thus, vertical integration increases spending not only through the increase in the administratively set price as existing evidence shows, but also by changing physician behavior to increase their throughput.

In summary, our analysis shows that integration negatively affects some important dimensions of care delivery, including quality and overall spending. Most notably, despite a significant increase in spending, we find that the patients of integrated physicians experience worse outcomes in some quality measures, such as rates of bleeding and other postprocedure complications. How can policy-makers avoid these unintended negative consequences of integration? To answer this question, we next examine the mechanisms behind our results.

7.2. Mechanisms for Changes in Postprocedure Complications

Insights from operations management literature suggest that changes in operational processes in the service system, such as increases in service speed and/or customer waiting time, can negatively affect the quality of service (KC and Terwiesch 2009, Chan et al. 2016, Song and Saghafian 2019). Because integrated physicians increase throughput while their patients experience worse outcomes, one potential explanation of the negative effects on patient outcomes might be the increase in the throughput, that is, speeding up the procedure. A second, not mutually exclusive, potential explanation is the reduction in deep sedation. The medical literature indicates several benefits of deep sedation during colonoscopies, including its fast onset of action, short duration of action, amnesic 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 postcolonoscopy complications is not established in the medical literature. Yet we examine the possibility that the reduction in deep sedation among integrated

providers may have resulted in increased patient complications. To examine this, we first included throughput as an independent variable and reexamined the effect of integration on patients' outcomes using the following model:

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

where $THRU_{jt}$ is the colonoscopy throughput per year for physician j in year t , and all variables are as previously defined. For examining the role of deep sedation, we use the following model:

$$Y_{ijt} = \alpha POST_{jt} + \delta SED_{ijt} + \beta X_{ijt} + \gamma Z_{it} + PHYSICIAN_j + MARKET_i + YEAR_t + \epsilon_{ijt}, \quad (5)$$

where SED_{ijt} is the binary variable for whether deep sedation was accompanied.

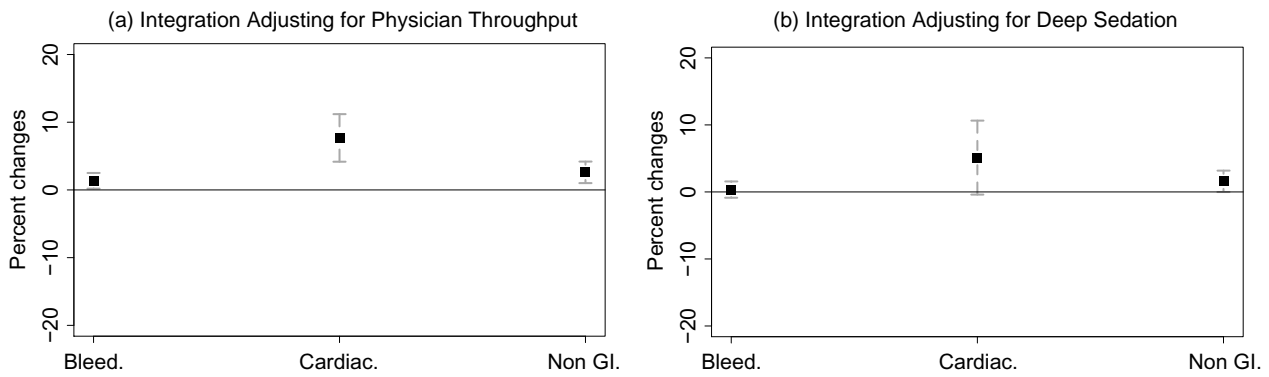
Our results presented in Figure 4 show that the effect of integration on patients' outcomes is either significantly reduced in magnitude or is no longer statistically significant after adjusting for deep sedation during the procedure, whereas the effect is consistent after adjusting for physicians' throughput. 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. These results suggest that the reduction in the use of deep sedation after integration (and not changes in throughput, e.g., a speed-up behavior) can at least partially explain an increase in some of the adverse patient health outcomes.

To further provide support for our claims, we implemented simple mediation models using the R package for causal mediation analysis developed by Tingley et al. (2014). Using a bootstrapping analysis of 10,000 iterations, we estimated the direct and indirect effects of integration via each of the potential mediators (throughput and deep sedation use) on our outcomes of interest (bleeding, cardiac complications, and nonserious GI complications). The results in Online Table EC9 confirm that integration had a significant effect (i.e., the 95% confidence interval for the size of indirect effect is positive and excludes zero) on deep sedation use, which, in turn, had a significant impact on both bleeding and other complications. When we examined the mediation effect of throughput, however, we observed that throughput does not mediate the effect of integration on these adverse outcomes.

7.3. Mechanisms for Changes in Process Measures

Given our finding that the reduction in deep sedation use postintegration partially explains an increase in adverse patient outcomes, we next take a closer look at the potential drivers of the changes in deep sedation itself. First, we examine whether the changes in physician

Figure 4. DID Estimates: Mediation Analyses



Notes. 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 year levels.

behavior in using deep sedation are driven by the changes within the integrated practice or if the changes are consistent across different practices. To examine this, we included an interaction term between the location of each colonoscopy (HOPD, OFFICE, or ASC) and integration to see if office procedures have a relative reduction in the use of deep sedation if the physician integrates. We find that the interaction term does not turn out to be significant, suggesting that the integration effect is driven by the changes that occur at the integrated practice, but the change does not spill over to other locations in which the integrated physicians practice (see Online Table EC10). In other words, this suggests that the reduction in deep sedation use is likely driven by the factors associated with the practice as opposed to the factors associated with the physician.

Based on such findings, we next examine what factors of the HOPD setting drive the reduction in deep sedation use. Compared with other types of sedation, deep sedation requires more resources and coordination effort because only anesthesiologists can administer it, whereas other types of sedation can be administrated by nurses. Thus, the provision of deep sedation is sensitive to anesthesiologists' availability within the organization. There are two potential channels through which anesthesiologists' availability postintegration might affect the care provided to the patients: (1) changes in the external margin (e.g., fewer total anesthesiologists) and (2) changes in the internal margin (e.g., less provision of deep sedation for colonoscopy per anesthesiologist). An example of the first channel is an integrated practice only using its own smaller number of anesthesiologists. An example of the second is an integrated practice shifting anesthesiologist volume to procedures other than colonoscopies.

To examine the first potential channel, we tested whether an integrated GI physician experiences a reduction in the total number of anesthesiologists or nurse anesthetists with whom the physician works. To this

end, for each GI physician, we first measured the total number of anesthesiologists who have worked with a GI physician in a given year.¹³ We found that, on average, a typical GI physician works with 6.6 anesthesiologists or nurse anesthetists per year. We next used a DID model similar to our main model but with the total number of anesthesiologists with whom an integrated GI physician works per year as the outcome variable to identify whether the change in integration affects this 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, $p < 0.001$), which suggests that the first channel is unlikely to drive the reduction in deep sedation use.

To examine the second channel, we measured the change in the rate of deep sedation exclusively for colonoscopy performed by an integrated versus independent anesthesiologist. We used a physician-level DID analysis in which the outcome is the number of deep sedations for colonoscopy per anesthesiologist per year, adjusting for anesthesiologist and year fixed effects. We find that, after an anesthesiologist integrates, the anesthesiologist provides deep sedation for 2.79 (SD: 0.22, $p < 0.001$) fewer colonoscopies per year (see Online Table EC11 for more details). Thus, these results suggest that, whereas integrated practices do not necessarily reduce the number of affiliated anesthesiologists, they shift their use of anesthesiologists to services other than colonoscopies. But why do they do so?

At least two explanations are possible. First, providers may shift the allocation of anesthesiologists because of the immediate financial gains from the FFS payment differential. This can happen if the immediate gains in providing anesthesia (e.g., anesthesiologists' reimbursement rate) for other procedures are higher than that for colonoscopy. This, however, is unlikely because Medicare pays anesthesiologists as a function of their time spent in the operating room. Thus, there is little financial

incentive for allocating anesthesia to different types of procedures to receive a higher payment. Furthermore, the average FFS Medicare payment for deep sedation per GI procedure via anesthesiologist involvement in HOPDs is generally low (only \$157.3 in 2012).

Second, integrated providers may shift the allocation of anesthesiologists for longer term financial gains. When the supply of anesthesiologists (a relatively expensive type of provider) is fixed and there are other specialty procedures that are more profitable than colonoscopy (e.g., orthopedics or pain management), the marginal financial benefit of providing deep sedation for colonoscopy procedures through an anesthesiologist may be low. In that case, organizations may allocate anesthesiologists to the services that generate greater overall revenue. To test this possibility, we examined the heterogeneity in the reduction of anesthesia among the practices with and without other specialties and found that physicians who integrate with a multispecialty clinic reduce deep sedation about twice as much (-0.037 , SD: 0.0069) as those who integrate with a single specialty clinic (-0.019 , SD: 0.0097) (see Table 6 for more details). This result implies that the second mechanism is more likely to be the reason behind the shift in the use of anesthesiologists to services other than colonoscopies. We do not, however, have access to data to directly establish a causal relationship in this regard and so leave it to future research to examine this phenomenon more rigorously. However, our conversations with gastroenterologists also confirm that the related scheduling and administrative processes for accessing anesthesiologists for colonoscopies are challenging because patients undergoing other procedures compete for their availability. Put together, all of our results suggest that modifying the underlying incentive structure can mitigate or prevent the adverse impacts of vertical integration. We discuss this in further detail in Section 9.

7.4. Mechanisms for Changes in Operational Efficiency

Our main result shows that, after integration, physicians increase their operational efficiency (throughput). We hypothesize that the increase in efficiency may be driven

by factors such as the changes in the use of deep sedation or in financial incentives. Although deep sedation is known to reduce the recovery time, it may increase the preparation time, and there is limited evidence on whether administering deep sedation for colonoscopy reduces the entire service time. By including deep sedation use in our main model, we can examine whether the changes in throughput are driven by the changes in the use of deep sedation. Because throughput is defined at the physician level, we calculated a per-physician aggregate measure of deep sedation use as the total number of colonoscopies that accompanied deep sedation out of the total number of colonoscopies provided by the physician in a given year.

Consistent with our main analysis, we find that integration increases throughput even after controlling for deep sedation use. Because deep sedation use is also associated with an increase in throughput (see Online Table EC12), this suggests that, if integration did not result in a reduction in deep sedation, there could be an even greater increase in throughput. We were not able to directly verify that an increase in financial incentive increases the throughput given that the price differentials were administratively set and consistent across all providers. Yet the fact that throughput increases controlling for deep sedation use suggests that the increase in throughput is likely driven by the increase in financial incentives rather than a reduction in deep sedation use. In particular, our finding implies that increasing payment for providing deep sedation can not only result in an improvement in quality, but also an increase in operational efficiency. We further examine the effect size in our counterfactual analysis.

8. Robustness Checks

To test the validity of our results, we performed robustness checks on various factors that can affect our results. As we describe next, our robustness checks include testing for changes in patient risk composition, investigating physicians' behavior (e.g., coding and gaming or retirement propensity), changing the measure of integration, examining the role of confounders such as the market

Table 6. Heterogeneity in the Reduction of Anesthesia by Single vs. Multispecialty Practices

	Dependent variable	
	sed	
	(1) Single-specialty	(2) Multispecialty
post	-0.019^{\dagger} (0.010)	-0.037^{**} (0.007)
Observations	1,805,880	636,702
R^2	0.527	0.590
Adjusted R^2	0.524	0.586
Residual Standard error	0.345 (df = 1,795,421)	0.322 (df = 630,123)

$^{\dagger}p < 0.1$, $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

competition, and inverse probability weighting as well as coarsened exact matching to adjust for the baseline differences in physicians. We also examined the impact of integration on patient experience to test whether integration affects other dimensions of care using the Outpatient Consumer Assessment of Healthcare Providers and Systems survey data for HOPDs (see Online Table EC16). The specific methods and results are provided in the online appendix. However, we next briefly discuss each of our main robustness checks. Overall, the results in this section give us confidence that our results are fairly robust and are not sensitive to our assumptions and model specifications.

8.1. Changes in Patient Risk Composition

One important assumption of our identification strategy is that the changes in the quality outcomes of physicians who alter their integration are not because of the changes in patient characteristics as a result of postintegration selection. Given that distance is one of the primary factors for patients' choice of physicians and the majority of physicians' physical locations do not change after integration, such concerns on patient selection before and after integration are likely mitigated. However, it is possible that the changes in the ownership status of a physician can result in attracting a different set of patients. If this happens, then most likely there will be changes in some of the observable composition of patients. Thus, by examining whether there are any changes in observable patient characteristics, we can also get a better understanding of whether the unobservable changes may be a significant threat to our identification strategy. To this end, we first examined the changes in observed patient composition when GI physicians integrate. For each physician, we tested whether the composition of the physician's patients with respect to certain characteristics (e.g., demographic, clinical) changed following integration using a physician-level DID model:

$$Y_{jt} = \alpha \text{INTEG}_{jt} + \beta \mathbf{X}_{jt} + \gamma \mathbf{Z}_{jt} + \text{PHYSICIAN}_j + \text{YEAR}_t + \epsilon_{jt}, \quad (6)$$

where Y_{jt} is a measure of patient composition for physician j in year t (e.g., percentage of physician j 's patients in that year that have certain characteristics). Other variables are defined the same as our main model.

Online Figure EC2 shows that integration was associated with some changes in demographic or clinical composition. In particular, integrated physicians face a significant increase in the proportion of dual patients and a reduction in the proportion of patients with high risk for CRC.¹⁴ Of note, the DID model used in our main analysis controls for such observable changes. Yet such changes suggest that potential unadjusted confounders might be present. Empirical evidence shows that patients' risk for CRC is the strong predictor of colonoscopy

outcomes (Johnson et al. 2013). Thus, if the unobserved changes in patient characteristics also alter in the same direction as the CRC risk after integration, the result suggests that the changes in patient composition would bias our results in a direction that underestimates the negative impact of integration on patients' colonoscopy outcomes. That is, our estimates on the magnitude of the negative effect of integration on patients' outcomes might be conservative (i.e., the actual negative impact might be worse than what our estimates suggest). Thus, our robustness checks give us confidence about the direction of our results: integration negatively affects patients' outcomes.

8.2. Physician Behavior

8.2.1. Preintegration Characteristics. We adjusted for the baseline differences in physicians and patients using inverse probability weighting (IPW).¹⁵ Importantly, to address the possibility that physicians with a different propensity for deep sedation adoption at baseline may make use of deep sedation differently after integration, we included physician's pretreatment adoption of deep sedation as one of the matching criteria. We also evaluated the results with the matched sample using the coarsened exact matching method. Our results using both IPW and coarsened exact matching are fairly consistent with our main findings (see Table 7).

8.2.2. Coding and Gaming. Another important consideration for our identification strategy is that physicians may change their coding behavior in a way that does not reflect true changes in quality, depending on the administrative infrastructure of the newly integrated system. To test this assumption, we made use of the primary condition only to reexamine the effect of integration on two outcomes, bleeding and minor complications. Next, we examined limiting the definition of bleeding to major bleeding only, which is less likely to be subject to change as a result of changes in coding intensity. Our results in Table 7 suggest that there is no evidence that the potential changes in the coding intensity after integration affects our main findings. Further, there is no good reason for physicians to change their coding behavior with respect to these two outcomes because they are not used for payment or other factors that can create specific incentives.

8.2.3. Reduced Work Time. We also tested if the shift to employment caused GI physicians to become 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 identified a total of 1,131 GI physicians (6.9% of the GI physicians in our data) who are likely to be on a path to retirement¹⁶ during our observation period and reran the analyses by focusing on them. We observe that these physicians' changes in throughput and the use of deep sedation after

Table 7. Robustness Checks Results

	Deep sedation	Bleeding	Cardiac	Nonserious GI
Behavior				
IPW	−0.037*** (0.005)	0.004** (0.001)	0.010*** (0.001)	0.003* (0.001)
Coarsened exact matching	−0.036** (0.006)	0.008* (0.004)	0.011*** (0.001)	0.004** (0.001)
Major bleeding	NA ^a	0.004 [†] (0.0017)	NA ^a	NA ^a
Exclude retiring physicians	−0.037*** (0.006)	0.004* (0.002)	0.003* (0.001)	0.003* (0.001)
Threshold				
Cutoffs at 1%, 99%	−0.015* (0.005)	0.004** (0.001)	0.001 [†] (0.001)	0.014*** (0.001)
Cutoffs at 5%, 95%	−0.041** (0.008)	0.001 [†] (0.001)	0.002* (0.001)	0.013*** (0.001)
Cutoffs at 15%, 85%	−0.039*** (0.007)	0.003** (0.001)	0.003* (0.001)	0.010*** (0.001)
Binary	−0.039*** (0.0057)	0.005* (0.0016)	0.003** (0.001)	0.0041** (0.0011)
Continuous	−0.139*** (0.020)	0.011 (0.007)	0.004* (0.002)	0.001 [†] (0.001)
First instance	−0.242*** (0.026)	0.063 (0.008)	0.006* (0.003)	0.002* (0.001)
Competition				
Low	−0.031* (0.009)	0.005* (0.002)	0.002* (0.001)	0.004* (0.001)
High	−0.041*** (0.005)	0.004 [†] (0.002)	0.002 [†] (0.001)	0.003 [†] (0.002)

Notes. 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.

^aResults are not subject to change.

[†] indicates marginally significant at $p < 0.10$.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

integration are similar to the nonretiring physicians and our main results are consistent when the retiring physicians and their patients are removed from the sample (see Table 7).

8.3. Defining Integration

8.3.1. Defining Integration. In our main analysis, we made use of specific threshold values on the integration intensity measure introduced in (1) (10% and 90% for partial and full integration, respectively) to define integration. Although these thresholds are supported by both our data and the literature on the practice patterns of GI physicians, we tested the sensitivity of our findings to these values. Specifically, we used the following alternative thresholds: 1% and 99%, 5% and 95%, and 15% and 85% for partial and full integration, respectively. Table 7 shows that varying the threshold does not affect our main findings. Next, we used a binary integration variable (independent versus 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 a way yielded integration effects similar to that of partial integration in our main analysis likely because the majority of integration cases in our data are related to partial integration as we note earlier. We also directly used the continuous integration measure defined in Equation (1) without imposing any threshold. This also showed consistent results with our main findings. Finally, we defined an integration event as the first instance of the use of an HOPD-based reimbursement for a physician who never had an HOPD-based reimbursement before in the data set and defined the procedures before the date as preintegration and the ones after

the event as postintegration. The main effects were still consistent under such definition.

8.3.2. Examination of Full Integration. In our main analysis, we focus on the integration among the physicians who change status from independent to partially integrated, the majority of integration cases in our data. Here, we separately examine the cases when partially integrated physicians become fully integrated. We do so by applying the same approach and model specification we used for our main analysis (our results for this case are presented in Online Table EC14). Unlike the partially integrated physicians in our main analysis who reduce deep sedation use and increase some of their patients' postcolonoscopy complications, fully integrated physicians do not reduce the use of deep sedation, nor do their patients experience any increase in complications. Moreover, despite experiencing an increase of \$75.40 in per-procedure spending driven by the administratively set price differentials, fully integrated physicians decrease their throughput after integration.

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, the focus of our main analysis. One potential reason is that a large proportion of full integration cases result in the physicians becoming hired into hospital-based outpatient practices. This likely involves a different payment scheme as well as changes in the work environment than the integration cases through acquisitions we study in our main analysis. However, our data are insufficient to rigorously test these and other possibilities, and we leave it to future research to shed further light on these issues.

8.4. Role of Competition

Integration can contribute to reduced 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 we observe by stratifying our sample into equal sizes of high versus low competition areas. We defined high and low competition areas as those that have higher and lower than median HHIs, respectively. We do not observe noticeable heterogeneous effects between these two groups (Table 7). This suggests that, if unobserved changes in the market structure are consistent with the changes in market competition, then market competition is most likely not a major driver of our main findings.

9. Policy Implications

Overall, our results paint a negative picture of vertical integration, showing that it decreases some important aspects of quality and increases spending. Our evidence also suggests that the negative impact of vertical integration is driven by the physicians' responses to 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 their care delivery process and patient outcomes if the payment 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 if the providers did not make behavioral changes after integration. If all GI physicians who did not provide deep sedation had done so, about 26 (SE: 1.2) bleeding, 29 (SE: 1.5) cardiac symptoms, and 12 (SE: 1.0) nonserious GI symptoms per 1,000 colonoscopies would have been averted.¹⁷ Using our estimate, we calculated the reasonable amount of incentive that can be provided to promote the provision of deep sedation based on an existing approach of cost-effectiveness analysis (Pandya et al. 2020). We first estimated the health gains or quality-adjusted life years (QALYs) resulting from increased use of deep sedation as follows. Suppose one could prevent the reduction of deep sedation use after integration by increasing financial incentives. Assuming 0.1 QALY as the maximum amount of utility loss associated with postcolonoscopy adverse outcomes (Graves et al. 2007) and using a figure that spending up to \$22,289 for a unit of QALY is considered by some to be cost-effective in developed countries (Bertram et al. 2016), we back-calculated the monetary level of acceptable incentives. Our estimate translates into the monetary value of 26.4×0.1 QALY gained per 1,000

patients $\times \$22,289/\text{QALY} = \588.40 . Thus, adding extra money up to \$588.40 to the current reimbursement amount for each colonoscopy to encourage the use of deep sedation among integrating physicians can be cost-effective.

In addition to the impact on quality, we also found that the increase in deep sedation can also increase the operational efficiency (throughput) of physicians. Thus, we estimated the effect of an increase in deep sedation use on the throughput using a similar counterfactual analysis. If integrated physicians do not reduce deep sedation use, each physician will have an additional 2.3 (SE: 0.2) increase in throughput. It is difficult to convert this number directly into monetary value, but given the current concerns on the supply of GI physicians that deter patients' access to colonoscopy, an increase in throughput as a result of integration suggests the social impact could be positive.

The estimated incentive size for providing deep sedation for a colonoscopy is more than half of the current average that Medicare pays to an HOPD for a colonoscopy (\$917). This estimate critically depends on the assumption that providing financial incentives can alter physicians' or practices' behavior in a way that an improvement in process or outcome measures is possible, that is, more anesthesiologists being available to provide deep sedation. Yet our estimate can provide an upper bound for the financial incentives that could be used for payment policies. As noted earlier, the current Medicare payment for anesthesiologists is based on their time spent in the operating room, not the procedures for which the anesthesia was performed. Thus, adjusting the price of anesthesia by procedure type might not be directly implementable for Medicare patients. Still, there are other ways to incentivize providers to adopt more recommended practices, for example, through value-based payment. The estimated incentive size to provide deep sedation, that is, more than half of the current average that Medicare pays to an HOPD for a colonoscopy, can be significant for the practices and, thus, is likely to alter the current physician behavior and remain beneficial from a societal perspective. Finally, it is also important to monitor whether such changes in financial incentive creates new unintended consequence by moving away the anesthesia use from other services for which anesthesia is also valuable. To do so, it is important to have a comprehensive approach in evaluating the incentive structure of integrated practices.

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

Table 8. (Color online) Summary of the Impact of Vertical Integration

	Outcomes	DID effect		Outcomes	DID effect
Process measures	Polypectomy	–	Operational efficiency	Time to complete	–
	Incomplete col.	–		Time to follow-up	–
	Deep sedation	↓			
Postprocedure complications	Perforation	–	Spending	Colonoscopies/year	–
	Bleeding	↑		Any services/year	↑
	Infection	–		Procedure types/year	↑
	Cardiac comp.	↑		Patients/year	↑
	Serious GI	–		Total	↑
	Nonserious GI	↑		Physician	↓
	Interval CRC	–		Facility	↑

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 segments. Our results provide a cautionary message that, when physicians financially integrate in response to these policies that use financial incentives, it does not guarantee that integrated practices will achieve superior patient outcomes. To achieve superior patient outcomes, there should be additional measures to (a) monitor postintegration physician behavior and quality and (b) align postintegration financial incentives. For example, CMS could require mandatory reporting of quality measures that are likely to be affected when practices integrate as a part of pay for performance schemes, which would enable them to monitor whether there are any drastic changes in the integrated organizations' delivery of care. Monitoring the quality is also critical if additional money is spent in order to incentivize the integrated practices to improve quality. The CMS can also implement payment policies that further promote the provision of a high-value care process for the integrated practices to incentivize physicians.

In closing this section, we highlight that some of the policies we find useful based on our data and analyses might have unintended consequences, and thus, more research is needed prior to implementing them. For example, a dramatic increase in reimbursement for deep sedation may lead to inappropriate use of it by providers and others. Similarly, it might increase the number of unnecessary procedures overall, leading to significant costs because of overtreatment. In addition, as we discuss in the next section, our study has significant limitations, and it is important for policymakers to take such limitation into account. Finally, policymakers should note that our findings regarding the use of propofol and its mediating effect on adverse quality outcomes (e.g., perforation, gastrointestinal bleeding, interval cancer, infection incidence, the incidence of cardiovascular symptoms and serious or nonserious GI symptoms after colonoscopy) should only be interpreted in the context of integration (and not as recommendations for the typical medical practice).

10. Summary of Main Findings and Limitations

Table 8 summarizes our findings, in which favorable changes are indicated in blue and unfavorable changes are indicated in red (see the online version for colors). Overall, our findings provide evidence that, by altering physician behavior, vertical integration adversely affects the quality of care and increases spending.

Our various sensitivity analyses show that our main findings are fairly robust and are unlikely to be importantly affected by our model specifications or assumptions. However, it is important to note that 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 study. Thus, caution is needed if one wants to generalize our results. Second, there are various limitations from the nature of the data we use as well as our empirical strategy of DID. Although we discuss why the concerns for biases from both data and methods are mitigated (Section 6.2) and conduct various robustness checks (Section 8), these do not entirely eliminate all threats to internal validity. For example, our physician efficiency measures are obtained from two different data sets, one of which is available only for the shorter observation period 2012–2015. Nonetheless, both data sets present a consistent direction for the effect of integration. The data limitation should be taken into account. 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 data set that can more reliably identify various characteristics of integrated entities apart in the future would be helpful. Finally, whereas we observe strong evidence behind the mechanism we identify, there might be other hidden

changes postintegration that we cannot fully rule out. Thus, other possibilities should not be ignored. We, thus, leave it to future research to run specific controlled experiments or use other ways to further test the validity of our findings. Future research can also contribute by examining the impact of integration among different physician reimbursement structures, identifying the optimal size of incentives, and investigating how vertical integration affects the quality from patients' perspectives. Given the importance of understanding how recent trends in vertical integration impact the healthcare sector, we expect to see more research in this vein in the near future.

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Endnotes

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).

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

³ Unique claims are defined as the claims with the same beneficiary ID, service date, and provider national provider identifier.

⁴ For example, in addition to rerunning our analyses by varying thresholds, we use (1) as a continuous instead of discrete variable. We also rerun our analysis by using a dichotomized version of integration (see, e.g., Section 8.3 for more details).

⁵ The guideline recommends against screening above age 85 (U.S. Preventive Services Task Force 2008). Thus, we removed those above age 85 when they received colonoscopy from our main analysis as they are likely to be clinically different from the rest. We also limited the analysis to those aged 65 or above because the Medicare beneficiaries under 65 are often sicker than a typical Medicare population. To ensure the observation of postprocedure 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.

⁶ 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 and training as well as patient characteristics, 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).

⁷ We obtained incomplete colonoscopies directly from the HCPCS modifier codes 53, 73, or 74 on colonoscopy claims. 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.

⁸ We used the presence of an anesthesiologist or a nurse anesthetist to identify anesthesiology involvement (Cooper et al. 2012, Khiani

et al. 2012). 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.

⁹ For our DID analysis, we limited the sample to 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.

¹⁰ 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).

¹¹ Among the 385,901 patients who received multiple colonoscopies, 166,918 (43%) received them from the same physician.

¹² Biopsy is defined as a colonoscopy with single or multiple biopsies (CPT 45380). Polypectomies were identified as colonoscopies with ablation (CPT 45383), hot biopsy forceps or bipolar cautery forceps (CPT 45384), or snaring (CPT 45385).

¹³ We include the anesthesia administered by either an anesthesiologist (CMS provider specialty code = 05) or anesthesiologist assistants/certified registered nurse anesthetists (CMS provider specialty code = 32). A GI physician and an anesthesiologist or a nurse anesthetist were considered to have worked together if they treated the same patient on the same date.

¹⁴ Medicare considers an individual at high risk if the individual 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.

¹⁵ We used a logistic model with preintegration characteristics of the patient, physician, and area to estimate the propensity score that each physician will integrate and weighed the entire study sample by the inverse probability of treatment weights. We truncated the propensity at the 99th percentile to address the unstable weights or for providers with a very low probability of receiving the treatment. Using the weighted sample, we estimated the average treatment effect from our main model using R package ipw (van der Wal and Geskus 2011).

¹⁶ We defined GI physicians who are highly likely to retire as physicians who have submitted any claims for at least one year but submitted no claims (including inpatient claims) for all subsequent years.

¹⁷ Using our main model, we examined the hypothetical scenario of all patients who did not receive deep sedation receiving them and predicted the probability of individual patients having adverse outcomes. Based on the predicted probability, we simulated the realized binary outcome of the patient having an adverse outcome, from which we calculated the population-level rates of adverse outcomes per 1,000 colonoscopies. A bootstrapping method was used to estimate the standard error.

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