The Effect of Bundled Payments on Provider Behavior and Patient Outcomes*

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We consider how health care providers respond to bundled payments. Using claims data from dialysis patients, we show that facilities halved their use of injectable anemia drugs following Medicare's transition from fee-for-service reimbursements to a bundle. We identify the causal effects of the payment reform using a novel instrumental variable — patients at higher elevations naturally require lower doses of anemia drugs — and find that lower doses caused a decrease in mortality but an increase in blood transfusions. Allocative efficiency increased from this change as providers reduced doses more for patients who benefit little from the drug.

JEL Codes: D43, I11, I18, L10

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1. Introduction

Health insurers use bundled payments to restrain reimbursement costs. Under a bundled payment system, providers receive a single reimbursement for an entire episode of care, with episodes typically defined as individual procedures like a joint replacement or chronic conditions like end stage renal disease (ESRD). Because bundled payments do not depend on the actual costs incurred during treatment, proponents of this system claim it encourages coordination among providers and reduces unnecessary expenses, virtues that have spurred Medicare's recent adoption of so-called alternative payment models for nearly 30% of its reimbursements (Shatto, 2016). Counteracting the possible advantages of bundled payments, however, is the incentive for providers to undertreat patients, as additional care does not yield any additional reimbursement. Given these inherent tradeoffs, we consider the precise ways in which providers reallocated resources in response to Medicare's adoption of a bundled payment system for dialysis, focusing specifically on how the reallocation affected patients' health and the costs for other parts of the health care system.

Before changing its payment model in 2011, Medicare reimbursed dialysis facilities with a hybrid system that gave providers a fixed payment for each dialysis session, a medical procedure that cleans the blood of patients with ESRD, and a fee-for-service payment for any injectable drugs administered during treatment. Most of these drugs were used to treat patients' anemia, a nearly ubiquitous condition among dialysis patients in which a lack of red blood cells reduces oxygen flow to the body's organs. The most common drug to treat anemia, epoetin alfa (EPO), was the largest prescription drug expenditure for Medicare prior to the bundle, totaling $2 billion in 2010 (U.S. Government Accountability Office, 2012). Administering EPO proved lucrative for providers, accounting for as much as 25% of revenue for the largest dialysis chain, DaVita, and up to 40% of its profits (DaVita, 2005). Many patient advocates raised concerns about the pervasive use of EPO, however, as excessive doses increase the risk of mortality and cardiovascular events (Besarab et al., 1998; Singh et al., 2006; Brookhart et al., 2010).

Partly as a result of unconstrained EPO reimbursements, Medicare's spending on the nation's 430,000 dialysis patients increased from $5 billion in 1990 to $33 billion in 2010, peaking at 7% of Medicare's overall budget. In response to these escalating costs, legislation enacted in 2008 set in motion an eventual payment reform for Medicare's ESRD program, split into two parts. First, in 2011, Medicare began bundling payments for anemia drugs with payments for dialysis treatments under the

new ESRD Prospective Payment System (herein referred to as the "bundle" or "PPS"). Second, to address concerns that the financial incentives from the bundle might harm patients if providers cut essential treatments to protect their profits, Medicare implemented the Quality Incentive Program (QIP) in 2012, which allows Medicare to reduce payments to facilities that fall below certain quality thresholds.

The move to bundled payments corresponded to a 49.1% drop in the average EPO dose given to patients each month from its peak during the fee-for-service era. Because Medicare simultaneously imposed the bundle on all providers, however, we cannot immediately identify the effect of the bundle on provider behavior and patient outcomes, as other contemporaneous changes could have coincided with the payment reform. And, although lower EPO doses reflect an unambiguous decline in the amount of resources used for dialysis treatments, the implications for patient welfare are less clear-cut: lower doses benefit those patients who were being overtreated prior to the reform but harm those whose anemia is now undertreated. Further complicating our attempts to measure the impact of the new reimbursement scheme, providers base their treatment decisions in part on a patient's underlying health, so any correlation between drug doses and outcomes may be biased by unobserved confounds. Reflecting this possibility, we show that OLS regressions of hemoglobin and blood transfusions on patients' EPO doses produce spurious negative and positive correlations, respectively, even though randomized controlled trials have shown that the drug in fact causes the opposite clinical response.

To overcome the empirical challenges stemming from coincidental changes in dialysis care and patients' unobserved health conditions, we use a novel source of exogenous variation in providers' treatment decisions to estimate the causal effect of bundled payments on EPO doses and outcomes: patients at higher elevations have higher baseline hemoglobin levels and are inherently more responsive to EPO (Winkelmayer et al., 2009; Brookhart et al., 2011). When providers received fee-for-service reimbursements for injectable drugs, this physiological distinction made patients at higher elevations less profitable for dialysis facilities, as clinical guidelines recommend that they receive smaller doses of EPO, and hence facilities received correspondingly lower fee-for-service reimbursements. After the switch to bundled payments, the financial incentives flipped, with patients at higher elevations becoming more lucrative for providers, because they naturally require smaller doses of EPO.

Although promising as a source of exogenous variation, elevation likely would not be a valid instrument on its own: just as elevation directly affects hemoglobin levels, it may also directly affect other health outcomes. In light of this, we use the interaction between elevation and the payment reform as

an excluded instrument while controlling directly for time trends and elevation in our first- and second-stage regressions. By instrumenting for EPO doses with the interaction term, our empirical strategy resembles a differences-in-differences estimation, with the first stage comparing EPO doses at facilities that typically use less of the drug due to their high elevation with those at lower elevations that typically use more of it, during the fee-for-service era when financial incentives favored higher doses relative to the bundle era when the financial incentives reversed.

From our first stage estimates, we find that facilities at lower elevations both use more EPO and disproportionately reduced their doses after the bundle. Our second stage then links the change in EPO to its effect on outcomes. For this specification to have a causal interpretation, the interaction between a facility's elevation and Medicare's payment policy must only affect health outcomes through its influence on EPO doses, conditional on other controls, and several pieces of evidence suggest that our empirical strategy satisfies this requirement, including parallel pre-trends for patients' EPO doses across high and low elevations.

Our instrumental variable results show that the bundle had a large effect on treatments and outcomes. In our most-conservative specification that includes patient fixed effects, the average post-bundle drop in EPO of 9.4% caused hemoglobin levels to fall by 1.0% and the number of blood transfusions to increase by 13.0%, suggesting worse management of patients' anemia. Part of the initial rise in transfusions reflects the profits at stake, as transfusions shift the costs of treating anemia from the dialysis facility (in the form of EPO) back to Medicare, given the reimbursement policies at the time that did not yet penalize providers for excessive transfusions.[1] For more acute outcomes, the decline in EPO caused a 3.5% decrease in hospitalizations from cardiac events and a 4.2% fall in mortality rates.

Establishing the causal effect of EPO on health outcomes allows us to extend our analysis to evaluate the bundle's effect on allocative efficiency, a key contribution to the literature on alternative payment models. With bundled payments making each dose of EPO a marginal cost rather than a marginal profit, facilities have a financial incentive to use less of the drug compared to when they received fee-for-service reimbursements. We find that, while facilities did use less EPO overall, the cuts were not applied uniformly across all patients: doses for patients who benefit the most from EPO fell 6.5%, whereas doses for those who benefit the least fell 14.9%. As a result, the bundle caused both a reduction in

[1]To isolate the effects of the payment reform from other related changes, we restrict our sample to 2009-2012 in this paper, which is largely before the QIP would have a meaningful impact on dialysis facilities. We discuss the QIP in more detail in Appendix A.

overall treatment intensity as well as a reallocation from low-benefit to high-benefit patients. Moreover, outcomes improved for the low-benefit patients due to their much lower doses of EPO: complications associated with excessive EPO doses (i.e., hospitalizations for cardiac events) dropped 21.8% even though complications associated with insufficient EPO doses (i.e., transfusion rates) fell 17.4%. Because health outcomes *improved* while overall Medicare spending *declined* for the patients with the largest decrease in EPO doses, we interpret this as an improvement in allocative efficiency. We further show that large for-profit dialysis chains accounted for the bulk of this reallocation.

Our results contribute to a recent literature examining the effects of Medicare's Bundled Payments for Care Improvement Initiative. Starting in 2011, this initiative sought to restrain health care costs by paying providers a bundled rate rather than a traditional fee-for-service reimbursement. Using observational data, Maughan et al. (2019) find that hospitals participating in the bundled payment initiative had worse outcomes for average patients than similar non-participating hospitals did, but not for the most vulnerable patients. Martin et al. (2018) show similar results for lumbar fusions, where patients treated at participating hospitals had higher readmission and repeat surgery rates than patients at comparable hospitals. By contrast, both Dummit et al. (2016) and Navathe et al. (2017) document reduced costs for lower extremity joint replacements, with no meaningful difference in quality at participating hospitals. The findings from these studies may be biased, however, as the hospitals that selectively opt in to bundled payments may have been particularly well suited to achieve savings. Because our research design allows us to estimate the causal effects of a mandatory bundle, we contribute to the existing literature that has mostly used observational data from a small number of hospitals that voluntarily participated in bundled payments.

One important exception to the observational studies of bundled payments is Finkelstein et al. (2018), who consider a randomized trial of a bundled payment model for lower extremity joint replacements. They find that patients treated at participating hospitals were less likely to be discharged to post-acute care, yielding a lower total cost of care with no differences in readmission or ER outcomes. Following this initial study, Einav et al. (2020b) show that the bundled payment program, which was originally implemented as a five-year randomized trial with mandatory participation by hospitals assigned to the new payment model but then unexpectedly made voluntary for half of these hospitals, is more likely to be adopted by hospitals that can increase revenue without changing their behavior and for hospitals that had large changes in behavior during the mandatory participation period. They find that

the voluntary regime generated inefficient transfers to hospitals and reduced social welfare compared to the status quo, but that alternative designs could make transfers more efficient. We complement these results by evaluating outcomes for a chronic condition that extends beyond the first year of bundled payments, considering the effects on total Medicare spending among all patients and providers (e.g., spillovers between dialysis facilities and hospitals), exploring heterogeneity across types of patients and providers (e.g., chain vs. independent facilities), and assessing several relevant clinical measures (e.g., hemoglobin levels and transfusion rates).

We also bridge the literature on bundled payments with a large body of work seeking to understand the causes of inefficiencies within the U.S. health care system. These papers have quantified and characterized various sources, including overuse (e.g., testing or treating too much) and misallocation (e.g., testing or treating the wrong patients).[2] Although prior work has advocated for policies that directly target the underlying inefficiencies (e.g., Garber and Skinner, 2008; Baicker et al., 2012; Glied and Sacarny, 2018), comparatively few empirical studies have examined how bundled payments, one of the most common types of payment reform, affect allocative efficiency. We contribute to this literature by presenting evidence of a costly misallocation, the overuse of injectable drugs for anemia management, and by showing how a bundled payment system improved the allocation of resources for one of the largest segments of Medicare, particularly Part B, which paid $26 billion for injectable drugs on a fee-for-service basis in 2015 (MEDPAC, 2017).

Our work also builds on the broad literature studying the effects of alternative payment models, including bundled payments. Many of these papers focus on Medicare's move in 1983 from cost-based reimbursements to the diagnoses related group (DRG) system for hospitals and its subsequent refinements (e.g., Cutler, 1995; Acemoglu and Finkelstein, 2008; Sloan et al., 1988a,b; Dafny, 2005; Eliason et al., 2018; Einav et al., 2018). In dialysis, the switch to a prospective payment system has also been studied extensively. For example, Chertow et al. (2016) document an abrupt decline in EPO doses beginning in late-2010 but find that all-cause mortality, cardiovascular mortality, and myocardial infarction did not change significantly, while Hirth et al. (2014) report an uptick in blood transfusions following the start of the bundle. Our quasi-experimental research design allows us to add to this literature by identifying the causal effect of the bundle on several health and spending outcomes.

[2]For recent examples of this work, please see Abaluck et al. (2016); Chandra and Staiger (2017); Currie and MacLeod (2013); Chan et al. (2019).

Finally, our paper contributes to a recent literature specifically focused on the economics of the dialysis industry (e.g., Eliason et al., 2020; Dai, 2014; Cutler et al., 2017; Dai and Tang, 2015; Grieco and McDevitt, 2017; Eliason, 2019; Wilson, 2016a,b). Of particular relevance, Gaynor et al. (2020) study how dialysis providers balance patient health with financial incentives for EPO using a structural model of dosing decisions. Using data from before the bundle, their findings suggest that traditional fee-for-service payments resulted in excessive EPO doses, with counterfactual simulations showing that doses would be 30–40% lower under the optimal linear contract. We complement their work by examining how the change in drug reimbursements affected providers' treatment decisions in practice, as well as the resulting impact on patient outcomes.

Our paper proceeds with Section 2, which discusses the institutional details of the U.S. dialysis industry. Section 3 describes the data used in our study and presents the findings from a preliminary time-series analysis of the payment reform. Section 4 presents results from our instrumental variable estimation of the causal effects of bundled payments. Section 5 then shows how the bundle affected allocative efficiency across patients and chains. Section 6 concludes.

2. Institutional Details of Dialysis

2.1. Medical Background on Kidney Failure

The kidneys filter wastes and toxins out of the blood and produce erythropoietin, a hormone that stimulates red blood cell production. For patients experiencing chronic kidney failure, the kidneys no longer adequately perform these functions. To survive, those with ESRD must either receive a kidney transplant or undergo dialysis, a medical treatment that mechanically filters wastes and toxins from a patient's blood, using one of two modalities. The most common, hemodialysis, uses a machine (also referred to as a station) to artificially clean blood outside the body, either at the patient's home or at a dialysis center, whereas peritoneal dialysis uses the lining of the patient's abdomen to filter blood inside the body.[3] Because over 90% of dialysis patients in the U.S. choose in-center hemodialysis, we focus on that modality for our analysis.[4]

[3]For more information, please see `https://www.niddk.nih.gov`.

[4]Please see Wang et al. (2018) for a discussion of the trends in dialysis modalities.

2.2. Medical Background on Anemia

Anemia results from deficient or dysfunctional red blood cells, which leads to reduced oxygen flow to the body's organs. Two blood chemical tests can be used to diagnose anemia and assess its severity: hematocrit and hemoglobin concentration. Hematocrit measures the volume of red blood cells as a percent of total blood volume, whereas hemoglobin concentration measures the amount of hemoglobin, a protein contained in red blood cells, in terms of grams per deciliter of blood (g/dL). The two measures are nearly isomorphic, with hematocrit approximately equal to three times the measured hemoglobin level (Bain et al., 2017). In this paper, we focus on hemoglobin levels.

According to accepted guidelines, anemia is defined as hemoglobin below 14 g/dL for men and 12 g/dL for women. Common symptoms relate to a patient's quality of life, including fatigue, weakness, headaches, difficulty concentrating, a rapid heart beat, and insomnia, but in some cases anemia can contribute to a greater risk of serious heart conditions, hospitalization, and death (Kliger et al., 2013).

Nearly all patients with kidney failure suffer from anemia. As mentioned previously, healthy kidneys produce erythropoietin, which stimulates the production of red blood cells in the bone marrow. Patients with kidney failure have much lower levels of naturally occurring erythorpoietin, which is why those on dialysis are often anemic (Babitt and Lin, 2006). Among these patients, anemia is typically managed using a cocktail of drugs, with acute instances requiring blood transfusions.

Chief among the drugs used to treat anemia is recombinant human erythropoeitin or epoetin alfa, a biologic commonly known as EPO. Manufactured by Amgen under the brand name EPOGEN®, EPO was approved by the Food and Drug Administration for the treatment of anemia in dialysis patients in 1989 (Kalantar-Zadeh, 2017), and since then has been a standard of care for the condition, with those treated with EPO requiring fewer blood transfusions and reporting improved appetite, activity level, and sense of well-being (Eschbach et al., 1987; Valderrabano, 2000). By 2005, 99% of in-center hemodialysis patients regularly received EPO, and in some years it represented the largest share of drug spending in Medicare's budget (U.S. Government Accountability Office, 2012).

By the mid-2000s, evidence from randomized controlled trials suggested that EPO may harm certain types of patients. In one study, Besarab et al. (1998) found that ESRD patients with congestive heart failure treated with EPO to achieve normal or high hematocrit levels had a higher probability of death and myocardial infarction. Similarly, Singh et al. (2006) found an increased risk of death and

cardiovascular events among patients treated with EPO to normal or high hematocrit levels who were diagnosed with chronic kidney disease but were not on dialysis. Although these randomized controlled trials focused on specific patient populations, they raised concerns about the use of EPO more generally, and in March 2007 the FDA issued a public health advisory for EPO, mandating a black box warning and advising physicians to adjust doses to target hemoglobin levels between 10 to 12 g/dL (Thamer et al., 2013). Over this period, observational studies suggested similar adverse effects (Zhang et al., 2004; Bradbury et al., 2009; Brookhart et al., 2010), although providers did not change doses much in response (Thamer et al., 2013). In June 2011, the FDA amended the original black box warning, instructing providers to use a dose no higher than what is necessary to avoid blood transfusions.

2.3. Elevation and EPO

ESRD patients do not respond uniformly to EPO, with the elevation at which a patient resides providing one source of variation. At higher elevations, the richness of oxygen in the blood decreases, activating an increase in both naturally occurring erythropoietin and the amount of iron in the blood stream. For those with healthy kidneys, erythropoietin stimulates bone marrow to use the available iron to produce red blood cells. In ESRD patients, however, a higher elevation is associated with increased iron availability but little increase in erythropoietin, because their kidneys do not properly perform this function. Still, iron makes both natural and artificial erythropoietin more productive, so patients at higher elevations tend to have higher baseline HGB levels and consequently receive less EPO.[5]

Several observational studies in the medical literature have documented this phenomenon. Brookhart et al. (2008), for instance, show that patients living above 6000 ft. receive 19% less EPO compared to patients at sea level, while Brookhart et al. (2011) find that patients moving from low to high elevations exhibit large and persistent increases in hematocrit and decreases in EPO doses relative to a comparison group. Moreover, Sibbel et al. (2017) find that even in 2012, after the 2011 payment reform, patients at higher elevations were less likely to receive EPO or intravenous iron, had higher mean hemoglobin levels, and had lower mortality rates compared to patients at lower elevations.

[5]Please see Winkelmayer et al. (2009) and Brookhart et al. (2011) for a more complete discussion of these physiological relationships.

2.4. The Market for Dialysis

Dialysis patients choose their provider much like they do in other segments of the U.S. health care system, with those covered under Medicare able to receive treatment at any facility that has an opening. Patients primarily receive dialysis at one of the more than 6,000 dedicated dialysis facilities across the country, where they typically go three times per week for treatment that lasts three to four hours each visit. These facilities are run by a mix of for-profit and non-profit firms, with the two largest for-profit chains, DaVita and Fresenius, controlling over 60% of facilities and earning 90% of the industry's revenue (United States Renal Data System, 2014; Baker, 2019). Independent facilities comprise most of the remainder.

Dialysis chains potentially have a number of advantages over independent facilities. Large chains, for example, may have lower average costs due to volume discounts for injectable drugs like EPO as well as centralized clinical laboratories; they may have a stronger bargaining position with commercial insurance companies (Pozniak et al., 2010); and their national brands and networks may make them more attractive to patients.

Chains also stand apart from independent facilities by having firm-wide standards that they implement across their facilities. Notably, large chains have operation manuals that dictate each of their facilities' procedures during treatment. Chains' system-wide standards may not universally lead to higher-quality care, however, as most quality measures decline at independent facilities after they are taken over by a large chain (Eliason et al., 2020).

2.5. Medicare Payment Reform

Since 1972, Medicare has extended full benefits to all patients with ESRD, regardless of age, paying for both dialysis and anemia treatment under Part B. Those enrolled in an employer group health plan when diagnosed with ESRD retain their commercial insurance as a primary payer for 33 months, during which time Medicare acts as a secondary payer before becoming the primary payer.

From the early 1980s to 2011, Medicare paid providers a composite rate of approximately $128 per session, which was intended to cover the labor, capital, supplies, and routine lab tests associated with each dialysis treatment. In addition, Medicare reimbursed providers for EPO and other injectable drugs on a fee-for-service basis. Prior to 2005, the reimbursement rate was based on the average

wholesale price. In 2005, this rate changed to the average sales price plus a 6% markup, resulting in a reimbursement rate of about $10 per 1000 IUs. EPO doses and expenditures increased consistently during the fee-for-service era, with spending on erythropoietin stimulating agents (ESAs), such as EPO, approaching $2.7 billion in 2007 (Whoriskey, 2012). Concerns that the distortionary incentives from fee-for-service reimbursements resulted in excessive costs for Medicare and harm to patients motivated policy makers to include ESRD payment reform as a part of the Medicare Improvements for Patients and Providers Act (MIPPA) in 2008.

MIPPA mandated the bundling of dialysis and anemia treatments into a single prospective payment. Under the new PPS, which started in 2011, providers receive a single payment for each dialysis treatment, initially about $230. This single payment was intended to cover the costs of both dialysis and injectable drugs, including EPO, that were separately billable before the reform. Medicare set the reimbursement rate to reduce total federal payments to dialysis providers by 2%.

To offset the incentives for providers to reduce their costs by providing lower-quality care following the switch to bundled payments, MIPPA also mandated the development of the QIP, which reduces payments to providers that fail to meet certain clinical standards, such as hemoglobin levels and hospitalization rates. Although the specific criteria assessed in the QIP change from year to year, in its inaugural year, 2012, the QIP standards focused on patient's urea reduction ratio (URR), a measure of the adequacy of dialysis filtration, and hemoglobin (HGB) levels. Under the QIP, Medicare reduces the annual payments to the facility between 0.5 and 2.0% if, for instance, the HGB levels of too many patients fall outside the regulated standards, with the size of the penalty determined by the extent of the shortfall. We discuss the QIP further in Appendix A, where we provide evidence that the QIP did not meaningfully contribute to the reduction in EPO doses during our sample period.

3. Data, Descriptive Statistics, and Time Trends

The main dataset used in our analysis comes from the U.S. Renal Data System (United States Renal Data System, 2019), a clearing house that collects and manages data from a variety of sources relevant to ESRD patients and health care providers. Included in these data are Medicare claims, treatment histories, patient attributes, and annual facility surveys. In addition, CMS Form 2728, known as the Medical Evidence Form, provides rich data on the health and clinical attributes of patients when they

begin dialysis. We also geocode facility addresses and extract the elevation of their locations using data from the U.S. Geological Survey (U.S. Geological Survey Center for Earth Resources Observation and Science, 2014).

Table 1 presents summary statistics for our variables of interest. We limit our sample to hemodialysis patients between the ages of 18 and 100 for whom Medicare is the primary payer. We further limit our sample to observations for which we observe all patient and facility characteristics used in our later analysis. These characteristics include demographic variables like age and gender, comorbidities like diabetes and cancer, patient behaviors like smoking and drinking, and facility characteristics like chain affiliation and elevation. Although in some figures we use data from 2005–2014 to provide a wider perspective, we conduct all statistical analyses on a sample restricted to 2009–2012, a four-year window centered on the start of bundled payments and ending before the QIP had a meaningful effect on providers. After these restrictions, our sample contains approximately 10 million patient-month observations. As will be important for our instrumental variable analysis in Section 4, the elevation of facilities varies substantially, with a standard deviation of 924 ft. We present summary statistics by elevation in Appendix B.

3.1. Time Trends

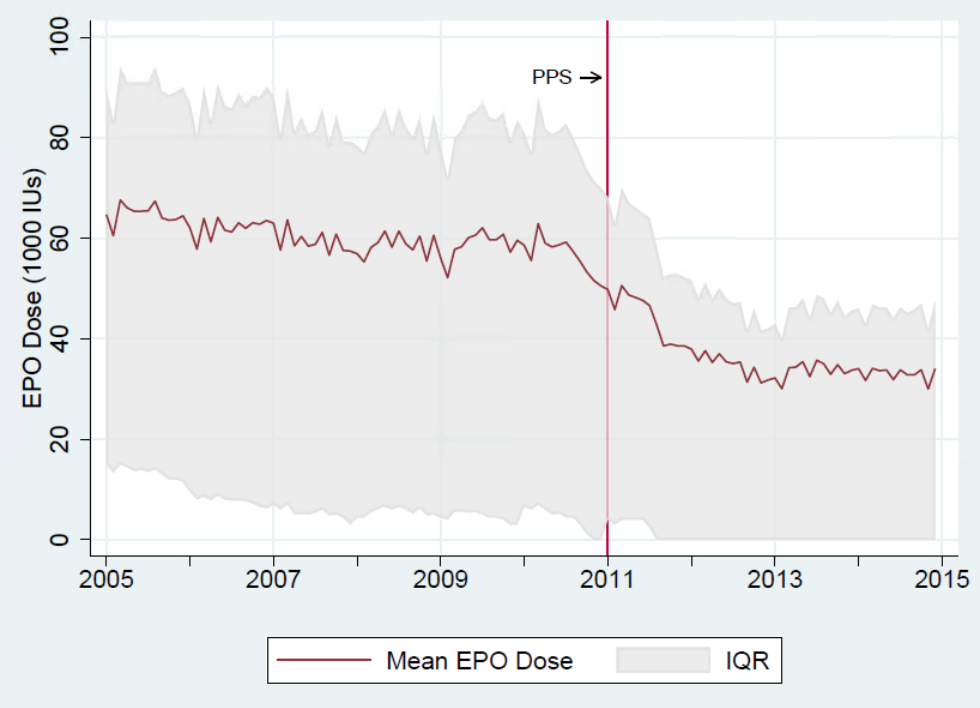
As Medicare specifically targeted EPO in its 2011 payment reform, the drug is a primary mechanism through which the policy affects both the allocation of resources and patient outcomes. Figure 1 shows the evolution of average EPO doses over time, along with the interquartile range. Doses followed a slow downward trend from 2005 to 2010, then, starting midway through 2010, this downward trend accelerated abruptly until leveling off around 2013. The sharp decline in EPO predates the payment reform in 2011 by a few months, as providers may have changed their behavior in anticipation of the payment reform. In our main analysis, we use January 2011 as the beginning of the bundle but show in Appendix C that our results are robust to changing the treatment period to include this anticipatory period as well. Also, as discussed in Section 2.2, during this period there were two other policy changes of note, a black box warning and the QIP. In Appendix A, we present evidence that these changes do not explain the decline in EPO doses in Figure 1 — if anything, they would make our estimate of the bundle's effect on EPO doses conservative.

Table 1
PATIENT DESCRIPTIVE STATISTICS

	Mean	Std. Dev.
Patient Characteristics		
Predicted Mortality	0.016	0.010
Age (Years)	63.40	14.57
Months with ESRD	45.08	38.01
Black	0.385	0.487
Male	0.552	0.497
Diabetic	0.540	0.498
Hypertensive	0.906	0.292
Incident Hemoglobin	9.853	1.674
Facility Characteristics		
Facility Elevation (ft)	638.1	923.5
Independent Ownership	0.197	0.397
Resource Use		
EPO Dose (1000 IUs)	48.27	63.14
Receives Any EPO	0.755	0.430
Medicare Spending ($)		
Total	7,555	10,769
Inpatient	2,558	9,380
Dialysis	2,287	970
Part D	465	817
Outpatient	394	1,266
Health Outcomes		
Hemoglobin (g/dL)	11.12	1.22
Mortality	0.016	0.124
Hospitalizations		
Any Cause	0.1380	0.3449
Cardiac Event	0.0271	0.1625
Septicemia	0.0094	0.0965
Transfusions		
Total	0.0282	0.1655
Inpatient	0.0232	0.1504
Outpatient	0.0057	0.0750
Emergency Room	0.0001	0.0098
Unique Patients	794,396	
Patient-Months	10,077,289	

Notes: An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Predicted mortality is the predicted value for each observation from a regression of mortality on patient controls and time fixed effects. Time fixed effects are not included in the prediction. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. Facility elevation is measured in feet above sea level.

Figure 1
Monthly EPO Doses Over Time



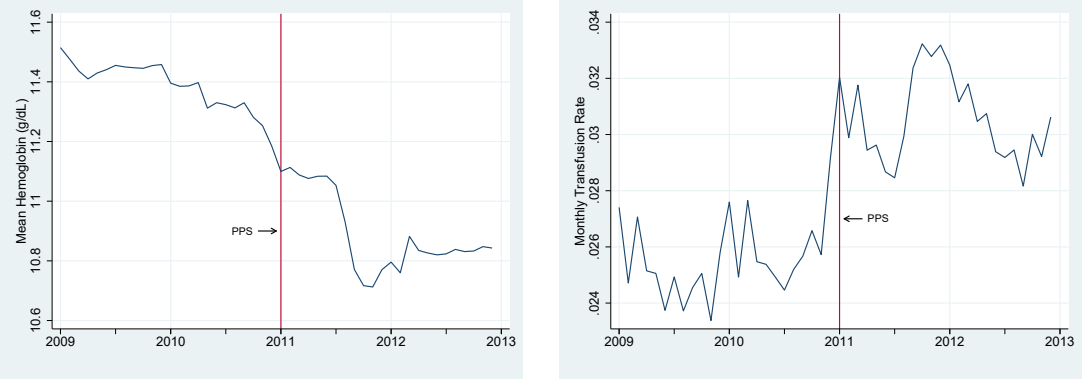
Notes: An observation is a patient-month. Sample consists of observations from January 2005 to December 2014 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. The vertical line indicates the start of PPS in January 2011.

Figure 2 shows the trends in hemoglobin and transfusions over time. As EPO is prescribed to increase patients' hemoglobin, the trends correspond to those of EPO. Leading up to 2011, we see a gradual decline in HGB levels and then a more-pronounced drop consistent with the much lower doses of EPO.[6] The second panel of Figure 2 shows an uptick in transfusions that aligns with the introduction of the bundle and the decline in EPO doses.

These trends suggest that providers responded to the bundle by cutting EPO doses, leading to a drop in HGB levels and an increase in transfusions. Although this suggests that outcomes deteriorated for at least some patients, to understand the full welfare implications of using fewer resources in dialysis treatments, we must disentangle how the change in EPO was distributed across patients. To this point, Figure 3 shows the amount of EPO given to patients for various HGB levels over time, with the largest decrease coming from patients with HGB levels above 12g/dL. As discussed above, patients with lower

[6]There appears to be a distinct drop in hemoglobin levels in mid-2011. We explore the timing of this drop in Appendix D and attribute it to the renegotiation of the sourcing contract for EPO between a specific large dialysis chain and Amgen, as other chains and independent facilities do not exhibit the same pattern.

Figure 2
Hemoglobin Levels and Transfusions Over Time



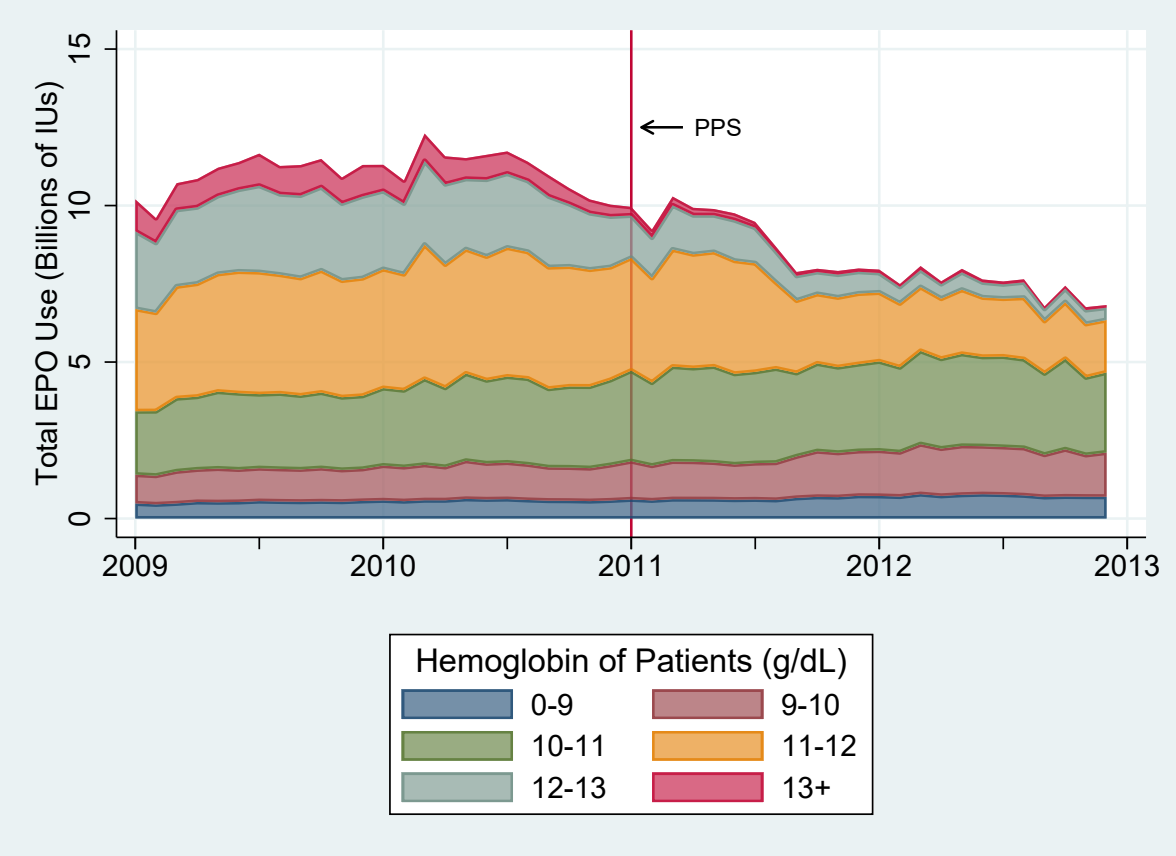
(a) Mean Hemoglobin Levels (b) Transfusion Rate

Notes: An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. The vertical line indicates the start of PPS in January 2011.

HGB levels benefit comparatively more from any given EPO dose, but for women with HGB levels above 10 g/dL and men above 12 g/dL, the potentially harmful side effects of EPO likely outweigh the drug's benefits.

In that sense, allocative efficiency may have improved following the bundle as providers concentrated the decrease in EPO among patients who were previously receiving doses that put them above the recommended range for hemoglobin levels. A purely descriptive approach such as this may obscure important mechanisms, however, as a patient's EPO dose is not exogenous: it depends on his or her previous EPO doses as well as any idiosyncratic response to the drug. For that reason, we use our instrumental variables to conduct a more thorough analysis of the allocation of EPO in Section 5.

Figure 3
EPO Use by HGB Level



Notes: An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. EPO doses are winsorized at the 99th percentile. Aggregate use for patients with hemoglobin in a given range is given in billions of IUs. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. The vertical line indicates the start of PPS in January 2011.

3.2. Preliminary Analysis of the Bundle

For a preliminary analysis of how the payment reform affected provider behavior and patient outcomes, we consider the following regression that includes an indicator variable for the post-PPS period, along with patient- and facility-level controls:

$$y_{ijt} = \beta_0 + \beta_1 \mathbb{1}[PPS_t = 1] + X_{ijt}\Gamma + \varepsilon_{ijt}. \tag{1}$$

Estimates of equation (1) appear in Table 2, with column (4) including controls for patient and facility characteristics, along with calendar month, patient, and facility fixed effects. This specification

Table 2
Effect of Bundle on EPO Dose

	(1) EPO	(2) EPO	(3) EPO	(4) EPO
PPS	-18.04***	-19.64***	-16.74***	-5.534***
	(0.242)	(0.235)	(0.414)	(0.263)
Pat/Fac Controls	0	1	1	1
Facility FE	0	0	1	1
Patient FE	0	0	0	1
Dep. Var. Mean	48.27	48.27	48.27	48.31
R-squared	0.0204	0.0784	0.136	0.532
Observations	10077289	10077289	10077264	10059269

Notes: OLS estimates from equation (1). Dependent variable is monthly EPO dose. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. PPS is an indicator variable for January 2011 or later. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. Facility controls include facility elevation, whether the facility to freestanding or hospital-based, and chain ownership status. Further controls include calendar month fixed effects. Facility and patient fixed effects are also included when indicated. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

suggests a decrease in EPO doses from the pre-bundle mean of over 9%. In Table 3, we present results from estimating the same specification for other dependent variables, finding large changes after the bundle: HGB levels decline 3.9%, transfusions increase 21.5%, overall hospitalizations drop 3.5%, hospitalizations for cardiac events decrease 6.6%, and the monthly mortality rate falls 4.8%.

Although easy to interpret, these initial time-series regressions may be biased by confounding time trends. In Figure 1, for instance, EPO doses begin falling prior to the start of the bundle. Moreover, Figure 1 suggests that the payment reform may have had both an effect on the level of EPO doses as well as the trend. In light of this, we enrich our prior specification by including a time trend interacted with the PPS indicator variable:

$$y_{ijt} = \beta_0 + \beta_1 t + \beta_2 \mathbb{1}[PPS_t = 1] + \beta_3 t_{Post\text{-}PPS} + X_{ijt}\Gamma + \varepsilon_{ijt}. \tag{2}$$

Equation (2) differs from equation (1) with the inclusion of two time trend terms, t and $t_{Post\text{-}PPS}$. Here,

Table 3
Effect of Bundle on Other Outcomes

	(1) HGB	(2) Transfusion	(3) Hosp., Any Cause	(4) Hosp., Cardiac Event	(5) Mortality
PPS	-0.442***	0.00538***	-0.00500***	-0.00195***	-0.000815***
	(0.00888)	(0.000201)	(0.000505)	(0.000210)	(0.000124)
Pat/Fac Controls	1	1	1	1	1
Facility FE	1	1	1	1	1
Dep. Var. Mean	11.12	0.0282	0.138	0.0272	0.0157
R-squared	0.0749	0.0118	0.0189	0.00721	0.00850
Observations	8181736	10077264	8869206	8869206	10077264

Notes: OLS estimates from equation (1). Dependent variable in column (1) is hemoglobin. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. Dependent variables in columns (2)–(5) are binary outcome variables. PPS is an indicator variable for January 2011 or later. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

t and $t_{Post\text{-}PPS}$ measure the number of months since the the start of the bundle in January 2011.[7] We therefore interpret β_1 as the average monthly change in EPO before the start of the bundle, while β_3 is the shift in this trend after the bundle. Complete estimates of equation (2) appear in Appendix E.

Column (1) of Table A12 presents results from estimating equation (2) with EPO as the dependent variable. We find that EPO doses were declining by approximately 0.4% each month prior to the bundle, which increases in magnitude to 1.4% each month after the bundle — in addition to the immediate decrease of approximately 13.8% in average EPO doses. Compared to our results from equation (1), this suggests the effects of the bundle on EPO doses did not become fully realized in January 2011, but instead evolved more gradually over time.

For other outcomes in Table A12, we see an increase in blood transfusions at the introduction of the bundle, which is consistent with the contemporaneous reduction in EPO doses, but this increase is paired with a reduction of the positive time trend for transfusions. For any-cause hospitalizations, we estimate a pre-existing downward trend. After the bundle, the magnitude of this downward trend increases, but without a significant level adjustment. Hospitalizations for cardiac events were also declining prior to

[7]The variable t takes on negative values prior to the start of the bundle in January 2011 such that in December 2010 $t = -1$, in November 2010 $t = -2$, and so on; $t_{Post\text{-}PPS}$ is set to 0 for all months prior to the start of the bundle. Please see Baicker and Svoronos (2019) for a discussion of the benefits of this definition of time trends.

the bundle, but the slope of this decline more than doubles post bundle, which is once again in line with the drop in EPO doses and the risks associated with the drug. By December of 2012, we find a 3.1% decrease in hospitalizations for cardiac events relative to December 2010. Finally, mortality rates were decreasing in the pre-period and declined further following the start of the bundle, though the difference is not statistically significant.

4. Instrumental Variables Analysis

Our descriptive results suggest that EPO doses fell sharply in response to bundled payments. But because all providers experienced the same change in reimbursements at the same time, isolating the reform's effects from other confounding, time-varying factors requires an empirical strategy built around exogenous variation in how the policy influenced some providers or patients differently than others.

4.1. Identification Strategy

Consider the effect of EPO on a health outcome, as in the following specification:

$$y_{ijt} = \beta_0 + \beta_1 EPO_{ijt} + X_{ijt}\Gamma + \varepsilon_{ijt}, \tag{3}$$

where y_{ijt} is the health outcome of patient i, treated at facility j, in month t. The main challenges with identifying the causal effect of EPO on health outcomes stem from reverse causality and simultaneity, which could bias OLS estimates in ambiguous ways. The estimates would be biased upwards, for example, if only the healthiest patients receive EPO. Or, a downward bias may result from unobserved confounds, such as rapidly deteriorating kidneys, that would lead to both high EPO doses to combat anemia as well as low survival rates due to the patient's declining health.

To overcome these empirical challenges, we use two independent sources of variation in EPO doses within an instrumental variables regression. First, we use the time-series variation in EPO reimbursements associated with Medicare's payment policies. As Medicare applied the change uniformly to all providers, rather than targeting specific payment changes to specific facilities, this policy introduced a plausibly exogenous shock to financial incentives. Second, we use a novel physiological aspect of anemia management: patients living at higher elevations have higher baseline levels of HGB and consequently

require lower doses of EPO to manage their anemia. As a result, facilities at low elevations experienced a larger shock to their EPO reimbursements than facilities at higher elevations did, and we can use the cross-sectional variation induced by patients' elevations along with the time-series variation induced by the payment reform to cleanly identify the effect of EPO on health outcomes.

We cannot simply use the payment reform and elevation as instruments directly in equation (3), however, as doing so would likely not satisfy the exclusion restriction for valid instruments. Causal inference using changes before and after Medicare introduced bundled payments would require us to assume that the policy reform only influences health outcomes through its effect on EPO. But changes in Medicare's reimbursement scheme are likely conflated with other trends, such as updated dialysis standards and related medical advances, which would be collinear with the payment reform. As such, any nonlinear changes over time could not be addressed with time fixed effects. Similarly, just as elevation directly affects patients' hemoglobin, it may also directly affect other health outcomes (although we have found no evidence in the medical literature suggesting that it does).

Rather than include each variable independently, we instead use the interaction of the post-bundle indicator variable and a facility's elevation as an instrument for EPO doses while controlling directly for time fixed effects and elevation in our first- and second-stage regressions. Our empirical strategy of interacting one variable with time-series variation and another with cross-sectional variation was first introduced by Card (1995) to measure the returns to education and used more recently, for example, by Nunn and Qian (2014) to study the effect of U.S. food aid on conflict in recipient countries and Bettinger et al. (2017) to study the effect of online college courses on student outcomes. Adapted to our setting, we have a first-stage specification of

$$EPO_{ijt} = \alpha_1 Elevation_j + \alpha_2 PPS_t + \alpha_3 Elevation_j \times PPS_t + X_{ijt}\Gamma + u_{ijt}, \tag{4}$$

where the instrument $Elevation_j \times PPS_t$ varies by facility and time period, allowing us to control for month-year fixed effects.

By instrumenting for EPO doses with the interaction term, our empirical strategy resembles a differences-in-differences estimation, with the first-stage estimates comparing EPO doses at facilities that typically use less of the drug due to their high elevation with those at lower elevations that typically use more of it, during the FFS era when financial incentives favored higher doses relative to

the bundle period when the financial incentives flipped. As outlined in Nunn and Qian (2014), the main distinction between this strategy and a typical differences-in-differences estimation is the continuous treatment variable.

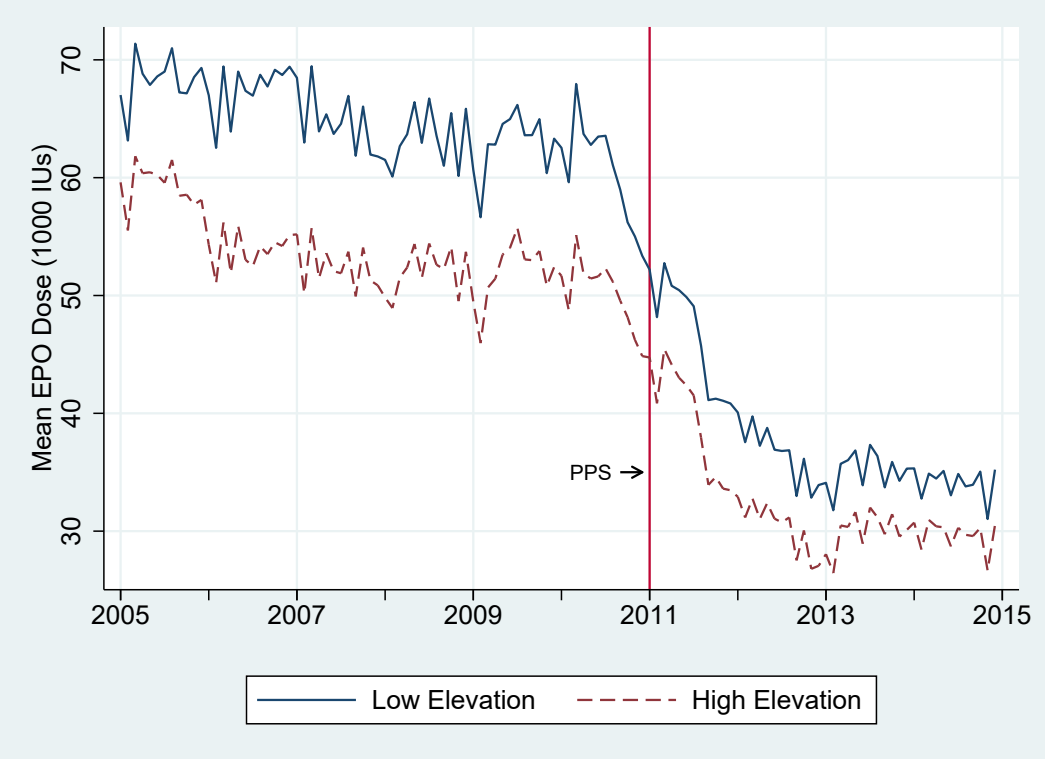
For our specification to have a causal interpretation, the interaction between a facility's elevation and Medicare's payment policy must only affect health outcomes through its influence on EPO doses, conditional on the controls. That is, the exclusion restriction in our setting requires that (i) any other mechanism through which elevation affects patients is constant over time and (ii) any other mechanism causing health outcomes to differ before and after bundled payments affects patients uniformly with respect to their elevation. As discussed above, if we were to use elevation alone as the instrument, the reduced-form slope would capture both the effect of EPO as well as other plausible mechanisms that affect health outcomes. For example, those living at higher elevations may have more-active lifestyles (e.g., hiking and skiing) that lead to better outcomes, or facilities may choose their location based on patients' potential outcomes. By interacting the two instruments, however, the reduced-form coefficient only measures how the slope between elevation and outcomes changes when facilities receive bundled payments. The main effect of elevation included in both the first and second stages differences out any other plausible mechanisms that are constant across the different payment schemes.

Although not directly testable, several pieces of evidence suggest that our empirical strategy satisfies these two requirements. In the same spirit as a traditional differences-in-differences estimation, for instance, a plot of EPO doses over time for the first and fifth elevation quintiles in Figure 4 shows parallel trends in EPO doses prior to the bundle. We see that, on average, low-elevation patients received higher doses of EPO before the bundle, with the difference between the two groups remaining constant during this time.[8] After Medicare's payment reform, average EPO doses declined in both quintiles, but the decline was much greater for low-elevation patients relative to those at high elevations. As discussed in Christian and Barrett (2017), non-parallel pre-trends would have suggested our differences-in-differences analog violated the exclusion restriction.

A related threat to our identification strategy would be omitted variables that change disproportionately across elevations over time. Based on balance tables for observable patient characteristics across elevation quintiles from before and after the bundle in Appendix B, we find that, although some

[8] A regression of EPO on facility elevation, a time trend, and the interaction of the two along with patient and facility controls using data prior to the bundle indicates that the difference in time trends is small and not statistically significant (p=0.6454).

Figure 4
Mean EPO Dose Per Month Over Time, by Elevation



Notes: An observation is a patient-month. Sample consists of observations from January 2005 to December 2014 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. High (low) elevation denotes facility elevation in the fifth (first) quintile. This corresponds to being above 870 (below 73) feet above sea level. The vertical line indicates the start of PPS in January 2011.

differences across elevations do exist and change over time, the changes are not systematically moving towards better or worse outcomes across elevations.

To assess more formally whether unobserved factors might potentially confound our analysis, we create a composite measure of a patient's health status from an OLS regression of mortality on observable patient characteristics and month-year fixed effects, which we call predicted mortality. We then use the estimated coefficients to predict a patient's mortality risk. Although we use only observable patient characteristics to construct the predicted mortality variable, predicted mortality is likely correlated with patients' unobserved characteristics that affect their health. To test if this measure changed differentially by elevation after the bundle, we estimate equation (4) with predicted mortality as the dependent variable. As shown in Table 4, we find that the differential change in predicted mortality

Table 4
Predicted Mortality by Elevation

	(1) Predicted Mortality	(2) Predicted Mortality	(3) Predicted Mortality
Facility Elevation	0.000000198***	0.000000185**	0.000000133
	(0.0000000581)	(0.0000000591)	(0.000000170)
Elevation × PPS	-0.0000000742***	-0.0000000495*	-0.0000000375*
	(0.0000000197)	(0.0000000229)	(0.0000000191)
Year-Month FE	0	1	1
Pat/Fac Controls	0	0	0
Facility FE	0	0	1
R-squared	0.000224	0.000473	0.138
Dep. Var. Mean	0.0157	0.0157	0.0157
Observations	10077289	10077289	10077264

Notes: OLS estimates from equation (4). Dependent variable is predicted mortality. Predicted mortality is the predicted value for each observation from a regression of mortality on patient controls and time fixed effects. Time fixed effects are not included in the prediction. PPS is an indicator variable for January 2011 or later. Facility elevation is measured in feet above sea level. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

by elevation is a precisely estimated zero, suggesting that changes in patients' underlying health are unlikely to confound our analysis.

Another violation of the exclusion restriction could come from facilities reinvesting the additional profits they earn from giving lower EPO doses after the bundle goes into effect. For instance, facilities at higher elevations use less EPO and therefore received disproportionately larger financial benefits from Medicare's switch to a prospective payment system that did not vary based on historical EPO doses; these facilities may have reinvested their financial windfall in ways that improved patient care. As shown in Table 5, however, we find no evidence that this happened, as conventional measures of a facility's investment in providing high-quality care, such as the number of patients per staff, the number of patients per station, and patient infection rates, do not differ by elevation, both before and after the payment reform.

Table 5
Facility Inputs by Elevation

	(1) Nurses Per Technician	(2) Patients Per Employee	(3) Patients Per Station	(4) Employees Per Station	(5) Hosp., Septicemia
Facility Elevation	-0.00000507	-0.0000504	-0.0000412	-0.00000317	-0.000000699***
	(0.0000143)	(0.0000335)	(0.0000588)	(0.0000124)	(0.000000129)
Elevation × PPS	0.00000758	0.0000230	-0.00000818	-0.00000646^{+}	0.0000000336
	(0.00000857)	(0.0000231)	(0.0000169)	(0.00000380)	(0.0000000786)
Year-Month FE	1	1	1	1	1
Pat/Fac Controls	1	1	1	1	1
Facility FE	0	0	0	0	0
R-squared	0.225	0.156	0.0870	0.0599	0.00283
Dep. Var. Mean	0.911	5.401	3.990	0.767	0.00939
Observations	242917	254307	256712	256173	10077289

Notes: OLS estimates from equation (4). PPS is an indicator variable for January 2011 or later. Facility elevation is measured in feet above sea level. For columns (1)–(4) an observation is a facility-month. For column (5) an observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. Facility controls include facility elevation, whether the facility to freestanding or hospital-based, and chain ownership status. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

4.2. Instrumental Variables Results

We present results from our first-stage estimates in Table 6, with an F-statistic of 32.7 demonstrating the instrument's relevance. Given the body's physiological response to elevation, EPO doses decrease with elevation in the expected way, but the rate of this decrease falls by half after the bundle. Following the first-stage estimates, we recover the local average treatment effect of EPO on patient outcomes using two-stage least squares. In addition to instrumenting for EPO_{ijt}, we control for several patient covariates, month-year fixed effects, and facility fixed effects and estimate this equation for the main outcomes of interest: HGB levels, blood transfusions, hospitalizations, and mortality.

The results for HGB levels highlight the relevance of our empirical strategy. Based on randomized controlled trials, the FDA-approved indication for EPO is to increase HGB levels. That is, larger EPO doses have been clinically proven to have a causal effect on this outcome. The OLS specification in Table 7, however, shows the opposite effect, which reflects the nonrandom assignment of EPO: more-anemic patients with lower HGB levels tend to be prescribed higher doses of EPO, inducing a negative correlation between HGB and EPO if relevant patient attributes are not observed in the data. Our IV strategy corrects for endogenous EPO doses, as shown in column (2). Increasing EPO doses by

Table 6
First Stage Regression

	(1) EPO	(2) EPO	(3) EPO
Facility Elevation	-0.00473***	-0.00350***	-0.00537***
	(0.000338)	(0.000398)	(0.00157)
Elevation × PPS	0.00141***	0.00131***	0.00137***
	(0.000212)	(0.000201)	(0.000198)
Year-Month FE	1	1	1
Pat/Fac Controls	0	1	1
Facility FE	0	0	1
R-squared	0.0299	0.0844	0.140
Dep. Var. Mean	48.27	48.27	48.27
Observations	10077289	10077289	10077264

Notes: OLS estimates from equation (4). Dependent variable is monthly EPO dose. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. PPS is an indicator variable for January 2011 or later. Facility elevation is measured in feet above sea level. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

1000 IUs per month increases a patient's HGB by 0.214 g/DL, on average, confirming the established medical fact that EPO effectively treats anemia. Table 7 also shows results with transfusions as the dependent variable. Similar to the results for HGB, the OLS coefficient suggests that EPO is associated with a need for more blood transfusions, once again contradicting established medical evidence. As with HGB, correcting for endogenous dosing decisions using our IV strategy reveals that larger EPO doses do indeed reduce the need for transfusions.

We show in Table 8 that larger EPO doses lead to more hospitalizations for cardiac events and higher mortality rates. For both all-cause and cardiac hospitalizations, the OLS and IV results suggest a positive correlation with EPO doses, although this effect does not remain statistically significant for all-cause hospitalizations in the IV specification. For mortality, the OLS estimates show a statistically significant, negative correlation with EPO, but the effect becomes positive while remaining statistically significant when we include our instruments. Interpreted as a local average treatment effect, our IV

Table 7
The Effect of EPO on Hemoglobin Levels and Transfusions

	HGB		Transfusion	
	(1) OLS	(2) IV	(3) OLS	(4) IV
EPO	-0.00308***	0.0214***	0.000134***	-0.000586***
	(0.0000258)	(0.00558)	(0.00000257)	(0.000157)
Year-Month FE	1	1	1	1
Pat/Fac Controls	1	1	1	1
Facility FE	1	1	1	1
Dep. Var. Mean	11.12	11.12	0.0282	0.0282
Observations	8181736	8181736	10077264	10077264
First-Stage F-statistic		32.73		48.24

Notes: OLS and IV estimates from equation (3). Dependent variable in columns (1)–(2) is hemoglobin. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. Dependent variable in columns (3)–(4) is a binary variable for receiving a blood transfusion. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

estimates suggest that the compliers — those patients whose EPO doses changed as a result of the instrument — had a 4.8% higher death rate during the pre-bundle period from excessive EPO doses.

As a placebo test, we also estimate equation (3) with septicemia, a severe blood infection, as the dependent variable. Because septicemia results from poor cleaning protocols at facilities and has no known relation to EPO, a statistically significant effect of EPO on septicemia would suggest an omitted variable confounds our analysis. As shown in Table 8, however, we do not find a causal effect of EPO on septicemia in our IV specification.

Taken together, our results highlight the tradeoffs associated with using EPO. Although EPO effectively treats patients' anemia, as reflected in higher HGB levels and fewer blood transfusions, these improvements must be weighed against a higher risk of cardiac events and death.

Table 8
The Effect of EPO on Hospitalizations and Mortality

	Hosp., Any Cause		Hosp., Cardiac Event		Hosp., Septicemia		Mortality	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
EPO	0.000163***	0.000205	0.0000167***	0.000185+	0.0000000928	0.0000358	-0.000115***	0.000129*
	(0.00000357)	(0.000254)	(0.00000124)	(0.0000962)	(0.000000617)	(0.0000549)	(0.000000910)	(0.0000644)
Year-Month FE	1	1	1	1	1	1	1	1
Pat/Fac Controls	1	1	1	1	1	1	1	1
Facility FE	1	1	1	1	1	1	1	1
Dep. Var. Mean	0.138	0.138	0.0271	0.0271	0.00939	0.00939	0.0157	0.0157
Observations	10077264	10077264	10077264	10077264	10077264	10077264	10077264	10077264
First-Stage F-statistic		48.24		48.24		48.24		48.24

Notes: OLS and IV estimates from equation (3). Dependent variables are binary outcomes. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

5. Changes in the Allocation of EPO

Because a primary reason policy makers adopt bundled payment systems is to curtail providers' inefficient use of resources, the sharp drop in EPO following the payment reform in dialysis ostensibly achieved this aim. If facilities reduced EPO doses indiscriminately across all patients, however, then the move to bundled payments may have been less effective than if they had instead focused their cuts on those patients who receive little benefit from the drug. To assess the bundle's impact on allocative efficiency, we extend our instrumental variable analysis to classify patients based on how responsive they are to EPO, in the sense that a given dose of EPO will have a large benefit for some patients while others may see no benefit at all. If providers concentrated their cuts on the latter group, then this suggests that the bundle increased allocative efficiency.[9]

5.1. Predicting Patients' Response to EPO

Consider health outcome Y_{ijt}, which depends on a provider input, EPO (E_{ijt}), as well as patient attributes like gender, age, and comorbid conditions (X_{it}) and provider characteristics like chain affiliation

[9]A formal analysis of allocative efficiency would require us to fully specify a welfare function while making strong assumptions about the tradeoffs associated with high EPO doses and the shape of the welfare function. Rather than take this approach, we look for evidence that the reallocation increased the returns to EPO, focusing specifically on transfusions and hemoglobin.

(F_{jt}), in the following way:

$$Y_{ijt} = f(E_{ijt}, X_{it}, F_{jt}). \tag{5}$$

We parameterize f as a linear function of EPO doses and patient attributes, where EPO and patient attributes are fully interacted, so that

$$Y_{ijt} = \beta_0 + \beta_1 E_{ijt} + \beta_2 X_{it} + \beta_3 E_{ijt} \times X_{it} + \beta_4 F_{jt} + \varepsilon_{ijt}, \tag{6}$$

which allows the marginal effects of EPO to vary based on patient attributes, with

$$\frac{\partial Y_{ijt}}{\partial E_{ijt}} = \beta_1 + \beta_3 X_{ijt}.^{10} \tag{7}$$

We conduct our analysis using the two dependent variables associated with anemia: HGB levels and blood transfusion rates. A patient's HGB level is a direct, though surrogate, measure of anemia that is readily available to providers during treatment, whereas reducing blood transfusions is a primary goal of treating anemia but more difficult to target directly. In this section, we focus on blood transfusions but provide a similar analysis for HGB levels in Appendix F.

To estimate equation (6), we extend our instrumental variable strategy from Section 4. As before, we estimate equation (6) using two-stage least squares where we treat E_{ijt} as an endogenous variable. The main difference from our approach in Section 4 is that we now interact E_{ijt} with all patient attributes in the data. To instrument for these interactions, we use the natural extension of our original instrument, elevation interacted with the bundle. That is, we interact our original instrument with each patient attribute and use these as a new set of instruments. For example, we instrument for the difference in the marginal effect of EPO for men and women using the differential change for men and women after the start of the bundle and across elevations. Using analogous instruments for all components of

[10]This specification only allows the returns from EPO to vary by patient attributes, not by facility characteristics. Different facilities may have production possibilities frontiers that are level-shifts of one another, but the slope does not change. Put differently, if a patient were to move from one facility to another, the level of the health outcome Y_{ijt} could change, but the marginal effect of EPO, $\partial Y_{ijt}/\partial E_{ijt}$, could not. This simplification reflects the physiological and institutional details of anemia treatment. The EPO molecule is the same across providers, and a patient's physiological reaction to a given amount of that molecule will be the same irrespective of which facility administers it. For any given patient, facilities have limited control over the effectiveness of EPO. The main way they can control how efficiently they use EPO is by deciding whom to treat and with how much.

$E_{ijt} \times X_{it}$, we estimate equation (6) and obtain the marginal effects outlined in equation (7) for each patient-month observation based on their observed attributes.

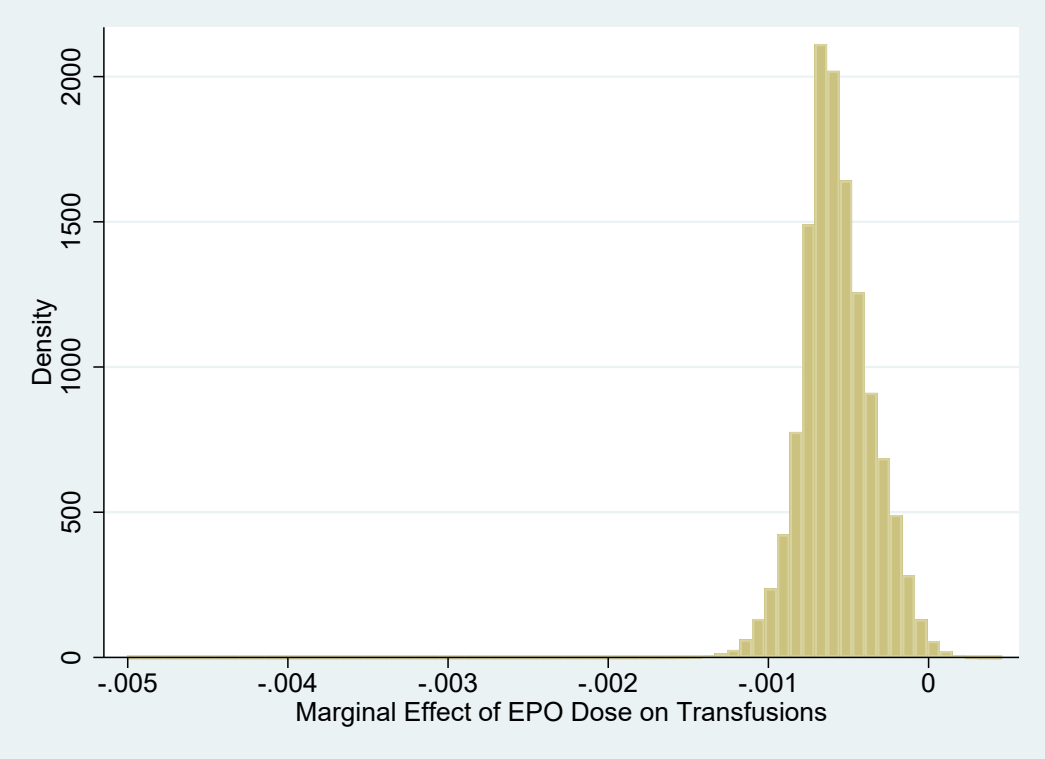
5.2. The Allocation of EPO and Its Effect on Blood Transfusions

Figure 5 shows the distribution of the marginal effect of EPO on blood transfusion rates for all patient-month observations. The average predicted marginal effect of EPO on transfusions is -0.0006, which is nearly identical to the local average treatment effect estimated in Section 4, with the distribution largely falling between -0.001 and 0. The wide variation in patients' responsiveness to EPO has important practical implications: the marginal effect of EPO is twice as large for a patient that is one standard deviation more responsive than the mean compared to a patient who is one standard deviation less responsive.

Most of the variation in marginal effects is between patients, with a given patient's responsiveness to EPO changing very little over time. In light of this persistence, we construct a time-invariant, patient-level measure of EPO responsiveness to evaluate allocative efficiency before and after the bundle. For this, we use the average of the patient-month predicted marginal effects obtained from estimating equation (6). To make it easer to interpret our results, we multiply the average marginal effects by -1 (since the benefit from EPO is a negative marginal effect on transfusions) and then normalize it by converting it to a Z-score, which we map to a patient's EPO-responsiveness type. Patients who are very responsive to EPO are those whose average marginal effects are larger (in absolute value), whereas patients who are relatively unresponsive to EPO are those whose average marginal effects are close to zero. Put differently, EPO is more effective at reducing transfusion rates for patients who are highly responsive to the drug.

The patients most responsive to EPO have different observable characteristics than those who are less responsive, as shown in Table 9 that compares the attributes of patients across responsiveness quintiles. Patients in the first quintile are the least responsive to EPO, meaning that EPO has only a small or negligible effect on their transfusion rates, and we call this group of patients "unresponsive." Conversely, we call patients from the fifth quintile "responsive." Along some dimensions, we see a negative association between how much EPO reduces the need for blood transfusions and the patient's observable health status. Unresponsive patients have the highest predicted and unadjusted mortality

Figure 5
Histogram of Predicted Marginal Effects ($\widehat{\frac{\partial Y_{ijt}}{\partial E_{ijt}}}$) of EPO on Transfusions



Notes: Predicted values are defined by equation (7) and come from IV estimates of equation (6). An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs.

rates, have more hospitalizations, are older, and have more-severe anemia as measured by incident hemoglobin (i.e., their HGB level before beginning dialysis). Throughout the sample, these unresponsive patients also receive the largest EPO doses yet still require the most transfusions, suggesting that EPO is largely wasted on them. Although possible that the transfusion rates for unresponsive patients would have been even higher had they not received such large doses of EPO, we show in our analysis below that this is not the case.

In Figure 6, we decompose the trends in EPO over time by patient responsiveness. Figure 6a shows that, although EPO doses fell for both groups, the drop was greater for the unresponsive patients. Prior to the bundle, unresponsive patients actually received more EPO than the responsive patients even though responsive patients receive a larger marginal benefit from the drug. The tendency to give more EPO to patients receiving little benefit from it diminishes after the bundle, as the two groups

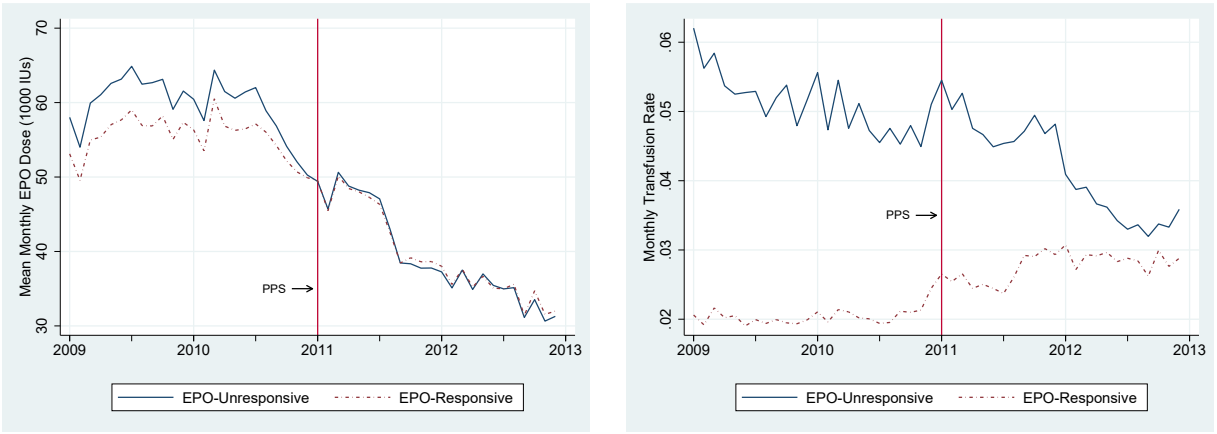
Table 9
Descriptive Statistics by Responsiveness of Transfusion Rate to EPO

	EPO-Responsiveness Quintile				
	First	Second	Third	Fourth	Fifth
Patient Characteristics					
Marginal Effect of EPO	-0.0002	-0.0004	-0.0005	-0.0006	-0.0008
Predicted Mortality	0.021	0.016	0.014	0.014	0.016
Age (Years)	68.08	63.39	62.30	62.10	63.72
Months with ESRD	22.75	45.05	45.46	43.73	44.11
Black	0.352	0.462	0.462	0.420	0.226
Male	0.645	0.613	0.579	0.513	0.461
Diabetic	0.520	0.516	0.516	0.522	0.556
Hypertensive	0.966	0.969	0.964	0.939	0.741
Incident Hemoglobin	9.696	9.633	9.776	10.013	10.308
Facility Characteristics					
Facility Elevation (ft)	681.8	640.1	625.6	634.2	629.7
Independent Ownership	0.224	0.210	0.213	0.211	0.234
Resource Use					
EPO Dose (1000 IUs)	61.20	60.51	59.24	58.38	55.90
Receives Any EPO	0.720	0.769	0.782	0.780	0.780
Medicare Spending ($)					
Total	10,117	7,572	7,094	6,976	6,964
Inpatient	4,459	2,631	2,305	2,252	2,258
Dialysis	2,079	2,257	2,279	2,271	2,241
Part D	321	408	429	434	439
Outpatient	454	379	355	336	344
Health Outcomes					
Hemoglobin (g/dL)	11.30	11.46	11.47	11.47	11.47
Mortality	0.042	0.014	0.012	0.013	0.014
Hospitalizations					
Any Cause	0.2243	0.1444	0.1302	0.1285	0.1304
Cardiac Event	0.0446	0.0286	0.0261	0.0264	0.0280
Septicemia	0.0195	0.0085	0.0070	0.0070	0.0073
Transfusions					
Total	0.0533	0.0250	0.0208	0.0197	0.0199
Inpatient	0.0445	0.0207	0.0169	0.0159	0.0159
Outpatient	0.0103	0.0048	0.0043	0.0042	0.0044
Emergency Room	0.0002	0.0001	0.0001	0.0001	0.0001
Unique Patients	44,996	46,812	52,642	55,423	56,631
Patient-Months	285,141	422,004	519,269	555,871	568,157

Notes: An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Predicted mortality is the predicted value for each observation from a regression of mortality on patient controls and time fixed effects. Time fixed effects are not included in the prediction. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. Facility elevation is measured in feet above sea level. Predicted values are defined by equation (7) and come from IV estimates of equation (6).

converge in terms of the doses they receive. As shown in Figure 6b, however, the drop in EPO only affects the transfusion rates for the responsive group: transfusion rates continued a downward trend for the unresponsive patients despite the fact that they had a larger drop in EPO compared to the responsive patients, for whom transfusions increased. These results suggest a marginal misallocation of EPO prior to the bundle since unresponsive patients experienced large decreases in their doses with no corresponding increase in transfusions. By contrast, transfusion rates increased for responsive patients, and these increases likely would have been even larger had they received the same proportional cuts in EPO that the unresponsive patients did.

Figure 6
EPO Dosing and Transfusion Rates Over Time by Responsiveness of Transfusion Rates to EPO



(a) Monthly EPO Dose

(b) Transfusion Rate

Notes: "EPO-responsive" ("EPO-unresponsive") refers to patients with average estimated marginal effects of EPO on transfusions in the fifth (first) quintile of absolute value. This corresponds to being at least 0.78 standard deviations above (0.73 standard deviations below) the average estimated marginal effect. Marginal effects are recovered from IV estimates of Equation 6. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. The vertical line indicates the start of PPS in January 2011.

To quantify how the bundle differentially affected patients based on their responsiveness to EPO, we estimate the following regression:

$$Y_{ijt} = \beta_0 + \beta_1 z_{\widehat{\frac{\partial Y_{ijt}}{\partial E_{ijt}}}} + \beta_2 \mathbb{1}[PPS_t = 1] + \beta_3 z_{\widehat{\frac{\partial Y_{ijt}}{\partial E_{ijt}}}} \times \mathbb{1}[PPS_t = 1] + \beta_4 t + X_{ijt}\Gamma + \varepsilon_{ijt}, \tag{8}$$

focusing on three dependent variables: EPO doses, transfusion rates, and mortality.[11] In this setup, EPO doses describe the intensity of treatment, while transfusion rates and mortality illustrate the resulting health outcomes. We include facility fixed effects and facility-level controls in X_{ijt}, as well as all other variables as defined in Section 3.1. Finally, we use two different approaches for including our standardized measure of EPO-responsiveness with respect to blood transfusions: (i) we include the measure as a continuous linear variable and (ii) we include a series of indicator variables for each individual's EPO-responsiveness quintile. Although we prefer the second specification because it is less parametric, it is also more cumbersome to interpret. As such, we include the linear estimates here in Table 10 and present highlights from the nonlinear estimates in Figure 7, with the complete tables for these estimates appearing in Appendix G.

Columns (1) and (2) in Table 10 suggest a misallocation of EPO prior to the bundle. Under fee-for-service reimbursements, patients with an EPO-responsiveness one standard deviation below the mean received, on average, 2.7% *more* EPO than patients at the mean. This pre-bundle gradient suggests that providers wasted EPO on unresponsive patients, whose transfusion rates do not respond to the marginal EPO dose. Although these patients appear to have received no direct benefit from the large doses of EPO, the facilities themselves benefited from the associated fee-for-service reimbursements. After the bundle, EPO doses declined overall, with providers reallocating EPO from unresponsive patients to those who benefit more from the drug, as seen in the positive coefficient on the interaction between the EPO-responsiveness Z-score and the PPS indicator variable. During the post-bundle period, patients with an EPO-responsiveness one standard deviation below the mean receive, on average, 0.9% less EPO than patients at the mean.

In columns (3) and (4), we show that, prior to the bundle, patients who responded more to EPO were less likely to need blood transfusions. After the bundle, the transfusion rate rose overall, but the patients experiencing the largest decrease in EPO also experienced the smallest increase in transfusion rates. Columns (5) and (6) show similar trends for mortality. Taken together, these results show that the decrease in EPO following the payment reform was so large that it caused comparatively more adverse outcomes among the EPO-responsive patients despite the reallocation of EPO towards them from the unresponsive patients.

Figure 7 shows analogous results based on estimates of the nonlinear version of equation (8). In the

[11] Please see Appendix G for other dependent variables: HGB levels, hospitalizations, and Medicare spending.

Table 10
Difference in EPO by the Responsiveness of Transfusions to EPO

	(1) EPO	(2) EPO	(3) Transfusion	(4) Transfusion	(5) Mortality	(6) Mortality
EPO-Responsiveness	-1.281***	-1.110***	-0.00988***	-0.00985***	-0.00826***	-0.00826***
	(0.104)	(0.104)	(0.000165)	(0.000165)	(0.000108)	(0.000108)
PPS	-6.189***		0.00484***		0.0000216	
	(0.272)		(0.000292)		(0.000182)	
EPO-Response × PPS	1.722***	1.361***	0.00421***	0.00416***	0.00442***	0.00442***
	(0.105)	(0.105)	(0.000180)	(0.000180)	(0.000110)	(0.000111)
Time Trend	-0.517***		-0.0000786***		-0.000109***	
	(0.0145)		(0.0000123)		(0.00000805)	
Facility Controls	1	1	1	1	1	1
Facility FE	1	1	1	1	1	1
Month FE and Trend	1	0	1	0	1	0
Year-Month FE	0	1	0	1	0	1
R-squared	0.123	0.125	0.00916	0.00919	0.00485	0.00486
Dep. Var. Mean	48.27	48.27	0.0282	0.0282	0.0157	0.0157
Observations	10077264	10077264	10077264	10077264	10077264	10077264

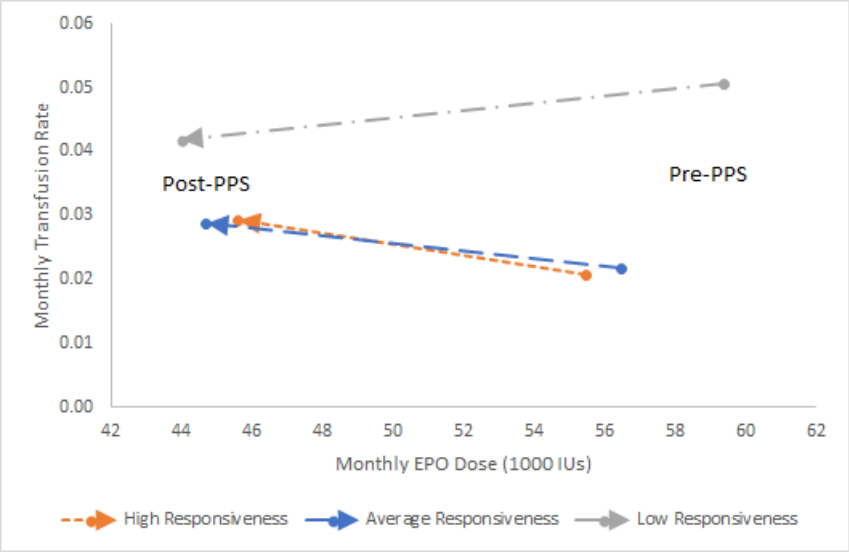
Notes: OLS estimates from equation (8). Dependent variable in columns (1)–(2) is monthly EPO dose. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. Dependent variables in columns (3)–(6) are binary outcome variables. PPS is an indicator variable for January 2011 or later. Time Trend is a continuous measure of months since January 2011. This means the value for January 2011 is zero, while it is positive for subsequent months and negative for prior months. Post-PPS Trend Change is the interaction of PPS and Time Trend. Estimated MFX Z-Score is the standardized patient-level estimated marginal effect predicted using the IV estimates of 6. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

pre-bundle period, patients in the lowest responsiveness quintile received the most EPO, whereas the most-responsive patients received the least. After the bundle, transfusion rates for the least-responsive patients fell 17.4% despite their comparatively larger drop in EPO doses. Adverse outcomes associated with excessive EPO also subsided for this group, with morality rates declining 37.9% and hospitalizations for cardiac events declining 21.8%, as shown in Figure A8 in Appendix G.[12] The large improvements in health outcomes for unresponsive patients stand in contrast to the changes for more-responsive patients, who experienced a statistically significant increase in transfusion rates accompanied by a relatively small increase in mortality, while cardiac hospitalizations also increased slightly, as shown in Figure A8.

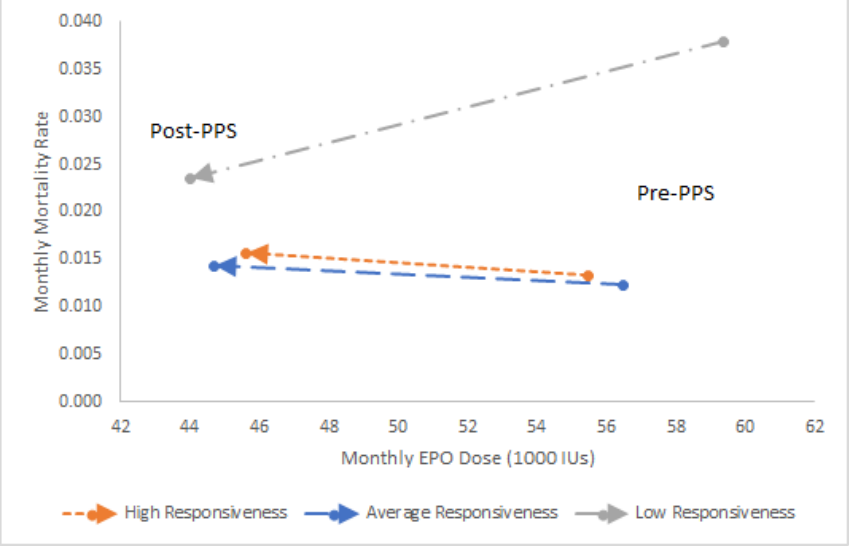
Our setting also allows us to consider how the bundle creates spillovers for other parts of the health care system not directly targeted by the payment reform. Most notably, those on dialysis often incur large inpatient and outpatient hospital expenses each year, much of which is directly related to EPO.

[12]Panel (a) of Figure A8 also shows that HGB levels fell more for EPO-responsive patients, consistent with their increase in transfusions.

Figure 7
Responsiveness Quintile Changes Across the Bundle



(a) Transfusion Rate



(b) Mortality

Notes: "High Responsiveness", "Average Responsiveness", and "Low Responsiveness" refer to patients with average estimated marginal effects of EPO on transfusions in the fifth, third, and first quintiles of absolute value, respectively. High-responsiveness patients have an average estimated marginal effect at least 0.78 standard deviations above the mean, while that of low-responsiveness patients is at least 0.73 standard deviations below the mean. Marginal effects are recovered from IV estimates of Equation 6 using a series of dummy variables for each responsiveness quintile, with these estimates presented in Table A20. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs.

We find compelling evidence of such spillovers. Figure A9, for example, shows that total spending on EPO-unresponsive patients fell 13.8% after the bundle, with the change primarily driven by the 25.5% decline in inpatient spending, reflecting the significant drop in cardiac hospitalizations stemming from the lower doses of EPO. In addition, the 9.4% decline in the average EPO dose from our most-conservative specification suggests that the bundle caused a 13.0% increase in transfusions, given the average treatment effect of EPO on transfusions. This represents a shift in anemia management from a treatment included in the bundle, EPO, to one excluded from it, transfusions.

5.3. Differences in Allocative Efficiency Across Chains

We also find that chain-owned facilities behave differently than independent facilities with respect to EPO, both before and after the bundle. Interacting the chain status of each facility with equation (8), we show in Table 11 that chains used much more EPO in the pre-bundle period and had a larger difference in doses across responsive and unresponsive patients. That chains gave relatively more EPO to unresponsive patients suggests they wasted more resources, as the higher doses did not lead to correspondingly lower transfusion rates. After the bundle, EPO doses decreased substantially at both chain and independent facilities, with chains cutting doses by nearly twice as much.

In contrast to independent facilities, where the difference in EPO doses for responsive and unresponsive patients changed only slightly after the bundle, chains reduced EPO doses significantly more for unresponsive patients. The lower doses caused transfusion rates to increase at independent and chain facilities at about the same rate, with the larger cuts for the least-responsive patients having an imperceptible effect on their monthly transfusion rates. Because chains reallocated more EPO away from unresponsive patients without increasing their need for transfusions, we interpret this as an improvement in allocative efficiency, perhaps reflecting a more-concerted effort at chain-owned facilities to reduce EPO costs once they no longer received fee-for-service reimbursements for injectable drugs.

Table 11

Difference in EPO by Responsiveness of Transfusions to EPO & Chain Status

	(1) EPO	(2) EPO	(3) Transfusion	(4) Transfusion	(5) Mortality	(6) Mortality
Chain Ownership	10.38***	10.98***	-0.00128	-0.00117	-0.000307	0.0000181
	(1.760)	(1.762)	(0.00104)	(0.000985)	(0.000493)	(0.000446)
EPO-Responsiveness	-0.490**	-1.017***	-0.0103***	-0.0104***	-0.00784***	-0.00787***
	(0.177)	(0.177)	(0.000356)	(0.000350)	(0.000253)	(0.000248)
EPO-Response × Chain	-0.997***	-0.120	0.000586	0.000654+	-0.000532+	-0.000499+
	(0.215)	(0.214)	(0.000402)	(0.000394)	(0.000279)	(0.000272)
PPS	-2.715***		0.00504***		-0.000356	
	(0.715)		(0.000647)		(0.000383)	
PPS × Chain	-4.307***		-0.000272		0.000469	
	(0.748)		(0.000697)		(0.000414)	
EPO-Response × PPS	0.677**	0.472*	0.00420***	0.00417***	0.00390***	0.00390***
	(0.229)	(0.238)	(0.000406)	(0.000404)	(0.000235)	(0.000234)
EPO-Resp. × PPS × Chain	1.305***	1.101***	-0.0000186	-0.0000400	0.000662*	0.000660*
	(0.257)	(0.265)	(0.000454)	(0.000451)	(0.000265)	(0.000263)
Time Trend	-0.287***		-0.0000565*		-0.0000841***	
	(0.0252)		(0.0000243)		(0.0000157)	
Time Trend × Chain	-0.282***		-0.0000240		-0.0000309+	
	(0.0240)		(0.0000258)		(0.0000162)	
Facility Controls	1	1	1	1	1	1
Facility FE	1	1	1	1	1	1
Month FE and Trend	1	0	1	0	1	0
Year-Month FE	0	1	0	1	0	1
R-squared	0.124	0.125	0.00916	0.00919	0.00486	0.00486
Dep. Var. Mean	48.27	48.27	0.0282	0.0282	0.0157	0.0157
Observations	10077264	10077264	10077264	10077264	10077264	10077264

Notes: OLS estimates from equation (8) with additional interactions with an indicator for chain ownership. Dependent variable in columns (1)–(2) is monthly EPO dose. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. Dependent variables in columns (3)–(6) are binary outcome measures. PPS is an indicator variable for January 2011 or later. Time Trend is a continuous measure of months since January 2011. This means the value for January 2011 is zero, while it is positive for subsequent months and negative for prior months. Post-PPS Trend Change is the interaction of PPS and Time Trend. Estimated MFX Z-Score is the standardized patient-level estimated marginal effect predicted using the IV estimates of 6. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

6. Conclusion

Dialysis facilities sharply reduced their use of injectable drugs after Medicare stopped reimbursing them on a fee-for-service basis. Once bundled payments made these drugs a marginal cost for providers, they responded by cutting doses the most for those patients who receive little benefit from the drug. In so doing, dialysis facilities revealed the extent of their wasteful behavior prior to the payment reform: health outcomes actually *improved* for the group of patients who experienced the largest drop in EPO.

Beyond dialysis, our results contribute to the broader discussion of alternative payment models within health care. Over the past decade, Medicare has responded to allegations that their traditional fee-for-service system resulted in an excessive use of resources — as we showed for injectable anemia drugs in dialysis — by promoting accountable care organizations and bundled payments, to the point that these alternative payment models now constitute over 30% of Traditional Medicare spending (Shatto, 2016). Using a research design built around the exogenous variation in EPO doses stemming from a patient's elevation, we show that allocative efficiency improved due to bundled payments. Other settings, like Medicare's bundled payments program for hip and knee replacements, have shown more modest reallocations (Einav et al., 2020b). As a chronic condition with potentially more scope for reducing the amount of resources used during the long time horizon of treatment, dialysis providers may be more willing to change their practice style in response to a bundle. Moreover, Medicare's payment policies may also influence facilities' treatment of privately insured dialysis patients, as Einav et al. (2020a) found for lower extremity joint replacements.

Our results also highlight the potential for the effects of bundled payments to spill over from one provider to another. As we documented here, the reduction in EPO doses led to an increase in transfusions and a decline in inpatient spending overall. Exploring the global impacts of payment reforms, and their potential to shift spending from one part of the health care system to another, is an important area for future research, as expanding the breadth of the bundle relates directly to Medicare's Comprehensive ESRD Care Model, a voluntary program aimed at evaluating the merit and feasibility of ACO-style organizations for dialysis patients.

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Appendix: For Online Publication

The following appendices provide additional robustness checks and details on our data.

Appendix A shows that neither the black box warnings nor the QIP can explain the patterns we observe for EPO doses.

Appendix B contains additional summary statistics by quintile of facility elevation.

Appendix C shows that our results are robust to a possible anticipatory response by providers.

Appendix D gives details on the supply agreements between providers and Amgen.

Appendix E presents additional time series results.

Appendix G contains additional tables and figures referenced in Section 5.

Appendix F repeats the exercise from Section 5 using equation (6) to estimate the effect of EPO on patients' end-of-month HGB levels.

Appendix H describes the use of other injectable drugs around the start of the bundle.

A. The Effect of Black Box Warnings & QIP on EPO

In this appendix, we present evidence that neither the black box warning nor the QIP contributes meaningfully to the decline in EPO doses shown in Figure 1. For the black box warning, four institutional details suggest that it did not cause the decrease in EPO around 2011. First, we show in Appendix H that other injectable drugs, which did not receive black box warnings, follow a pattern similar to EPO's after the bundle. Second, as we discuss in Section 2.2, the FDA has issued two black box warnings for EPO, both of which recommended providers use EPO more judiciously, but the evolution of EPO doses in Figure A1 shows that they did not change following the first black box warning in 2007, an instance when the label changed but financial incentives did not. Third, the decline in EPO begins in October 2010, eight months before the black box update, and it is unclear why providers would have changed their behavior in anticipation of the new black box warning even if they had been aware of the FDA's looming decision given that they did not change their behavior following the first black box warning. Finally, in Appendix D we show that a coincidental drop in EPO stems from one large chain that renegotiated its contract with drug supplier Amgen in mid-2011, as other chains and independent facilities do not exhibit the same patterns for EPO doses.

The other policy change around the start of the bundle was the QIP. As we explain in Section 2.5, Medicare instituted the QIP along with bundled payments to provide facilities with incentives for maintaining high-quality care while still restraining reimbursement costs. In contrast to the PPS that focuses on cost containment, the QIP aims to promote a high standard of care by reducing payments to poorly performing facilities.

To implement the QIP, each year Medicare announces the various performance measures that will comprise a facility's Total Performance Score (TPS). Facilities whose scores fall short of the benchmark that year face a reduction of their Medicare reimbursements of between 0.5–2.0%, depending on extent of the shortfall. During the sample period for our paper, Medicare used three clinical measures to construct the TPS: the percentage of patients with (i) HGB below 10 g/dL, (ii) HGB above 12g/dL, and (iii) URR above 0.65. For the first year of the QIP in 2012, Medicare used the facility's performance on these measures in 2010 to construct the TPS. For 2013 and 2014, only the latter two measures were used (based on facility performance in 2011 and 2012, respectively), with Medicare dropping low HGB levels as a criteria. The QIP also included a measure of vascular access in the TPS for 2014, although

vascular access has no relation to EPO, so we do not discuss it here.

Although Medicare introduced the QIP to discipline facilities' behavior, Figures A2a and A2b show that it did not cause the decline in EPO doses during this period — if anything, the QIP likely makes our estimate of the bundle's impact on EPO doses a conservative one. In Figure A2a, which shows the percentage of patients with HGB greater than 12 g/dL, we see no change in trend following the announcement of this performance measure in 2010; likewise, after its removal in 2015, the trend also did not change. Because EPO directly affects patients' HGB levels, the fact that the trend in the proportion of patients with high HGB levels remained constant both after facilities began receiving penalties and after the penalties were removed suggests this standard had little impact on dosing decisions.

Figure A2b next shows the percentage of patients with HGB less than 10 g/dL.[13] Again, facilities did not respond to the metric's introduction, with the trend remaining constant throughout 2010, although we do see evidence consistent with facilities responding to the metric's removal in 2011. The sharp rise in patients with HGB less than 10 g/dl after Medicare removed this metric from the QIP suggests that (i) our estimates of the bundle's impact on EPO and outcomes are potentially understated, because facilities may have continued giving EPO to low-HGB patients to avoid QIP penalties, and (ii) direct financial incentives from reimbursements predominately dictate facilities' dosing decisions, as facilities cut EPO doses to reduce their drug costs immediately upon Medicare's removal of the low-HGB guardrails.

As a final piece of evidence that the QIP did not drive dosing decisions, we point to the way facilities treated EPO-unresponsive patients after the bundle was introduced. Independent of any HGB criteria from the QIP, facilities cut EPO doses the most for patients whose blood levels did not change in response to EPO, as we show in Section 5 and Appendix F. By concentrating the cuts in EPO on patients whose blood levels would remain unaffected, facilities revealed that reducing drug costs rather than avoiding QIP penalties precipitated their treatment decisions.

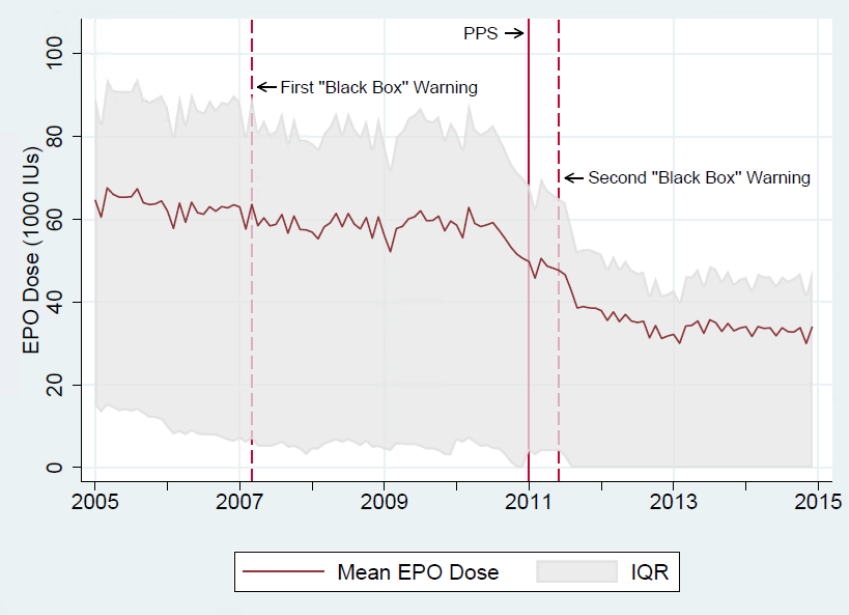
That the QIP had a negligible influence on facilities' behavior reflects the fact it had a limited scope for affecting their profits. With facilities receiving monthly Medicare reimbursements of approximately $2370 for each patient, even the maximum 2% penalty would reduce payments by only about $50 per patient per month. By contrast, the average change in EPO doses from 2009 to 2012 of 23,880 IUs per

[13]The removal of the measure relating to the percentage of patients with HGB below 10 g/dL was announced in July 2011 and retroactively applied to the performance year beginning January 2011. This means that the TPS calculated using facilities' performances from January to December of 2011 did not include the percentage of patients with HGB below 10 g/DL, but facilities did not learn that this measure would not be used until midway through the year. This proposed rule change was finalized by Medicare in November 2011.

month amounted to cost savings of $187–219 for the typical patient each month, given the wholesale cost of $7.85–9.19 per 1000 IUs of EPO estimated by Eliason et al. (2020). Even with the QIP penalties for substandard hemoglobin levels, the bundle created a much stronger financial incentive for facilities to reduce EPO doses.

In short, although the black box warning in 2011 and the QIP performance measures applied to 2010–2012 could have potentially confounded our analysis of the payment reform's effect on EPO doses, we find little evidence that they did, and, if anything, they suggest our results may be conservative. Moreover, because Medicare introduced the QIP in conjunction with the PPS, any potential confounding from the QIP would simply add nuance to our interpretation of the reforms rather than undermine our main findings. That is, we find that the financial incentives from the payment reform had a much stronger influence on facility behavior than the penalties from the QIP did, which provides valuable insights to policy makers aiming to restrain reimbursement costs while maintaining high standards for care. We consider the full effects of the QIP in Eliason et al. (2020).

Figure A1
Monthly EPO Doses Over Time with Black Box Warnings



Notes: An observation is a patient-month. Sample consists of observations from January 2005 to December 2014 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. Vertical dashed lines indicate the release of official warnings from the FDA about the safety of high EPO doses. The vertical line indicates the start of PPS in January 2011.

Figure A2
QIP HGB Performance Measures

(a) HGB > 12 g/dL Over Time

(b) HGB < 10 g/dL Over Time

Notes: Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. An observation is a patient-month. Sample consists of observations from January 2006 to December 2015 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Vertical lines indicate the introduction and removal of the QIP performance measure.

B. Summary Statistics by Elevation

We provide additional summary statistics from our data by quintile of facility elevation. We see that patients at higher elevations tend to be less healthy than those at lower elevations, but these differences do not change following the start of bundled payments. We do, however, see outcomes change differentially by elevation, providing descriptive evidence that the policy had different effects depending on a patient's elevation.

Table A1
Patient Descriptive Statistics by Elevation

	Elevation Quintile					
	First	Second	Third	Fourth	Fifth	Total
Patient Characteristics						
Predicted Mortality	0.015	0.015	0.015	0.016	0.017	0.016
Age (Years)	63.41	63.60	62.91	63.53	63.57	63.40
Months with ESRD	45.59	45.35	45.72	45.49	43.22	45.08
Black	0.447	0.440	0.452	0.375	0.211	0.385
Male	0.553	0.548	0.545	0.551	0.562	0.552
Diabetic	0.526	0.534	0.536	0.544	0.560	0.540
Hypertensive	0.910	0.906	0.909	0.905	0.900	0.906
Incident Hemoglobin	9.755	9.786	9.806	9.901	10.018	9.853
Facility Characteristics						
Facility Elevation (ft)	29.4	143.7	436.1	713.5	1875.9	638.1
Independent Ownership	0.185	0.183	0.177	0.231	0.208	0.197
Resource Use						
EPO Dose (1000 IUs)	51.26	50.01	50.68	46.61	42.70	48.27
Receives Any EPO	0.791	0.784	0.779	0.725	0.694	0.755
Medicare Spending ($)						
Total	8,019	8,042	7,342	7,389	6,980	7,555
Inpatient	2,788	2,759	2,443	2,469	2,328	2,558
Dialysis	2,320	2,372	2,266	2,262	2,215	2,287
Part D	499	493	464	442	428	465
Outpatient	352	389	410	424	394	394
Health Outcomes						
Hemoglobin (g/dL)	11.11	11.11	11.12	11.12	11.16	11.12
Mortality	0.015	0.015	0.015	0.016	0.017	0.016
Hospitalizations						
Any Cause	0.1406	0.1382	0.1355	0.1418	0.1340	0.1380
Cardiac Event	0.0280	0.0281	0.0268	0.0280	0.0248	0.0271
Septicemia	0.0097	0.0095	0.0091	0.0095	0.0090	0.0094
Transfusions						
Total	0.0297	0.0282	0.0278	0.0281	0.0270	0.0282
Inpatient	0.0255	0.0242	0.0226	0.0225	0.0210	0.0232
Outpatient	0.0047	0.0045	0.0059	0.0064	0.0068	0.0057
Emergency Room	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Unique Patients	182,367	177,043	181,696	184,327	185,625	794,396
Patient-Months	2,043,637	1,989,978	2,033,229	2,000,408	2,010,037	10,077,289

Notes: An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Predicted mortality is the predicted value for each observation from a regression of mortality on patient controls and time fixed effects. Time fixed effects are not included in the prediction. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. Facility elevation is measured in feet above sea level. The cut points between elevation quintiles are 73, 260, 599, and 870 feet above sea level.

Table A2
Patient Descriptive Statistics by Elevation, 2009

	Elevation Quintile					
	First	Second	Third	Fourth	Fifth	Total
Patient Characteristics						
Predicted Mortality	0.015	0.015	0.015	0.017	0.017	0.016
Age (Years)	63.44	63.57	62.98	63.65	63.83	63.49
Months with ESRD	42.29	42.25	42.39	42.53	40.03	41.90
Black	0.446	0.438	0.447	0.370	0.207	0.382
Male	0.550	0.546	0.543	0.549	0.559	0.549
Diabetic	0.510	0.524	0.524	0.531	0.549	0.528
Hypertensive	0.908	0.905	0.910	0.904	0.899	0.905
Incident Hemoglobin	9.836	9.855	9.866	9.975	10.094	9.925
Facility Characteristics						
Facility Elevation (ft)	29.8	143.3	437.8	714.2	1868.8	638.0
Independent Ownership	0.199	0.202	0.195	0.267	0.229	0.218
Resource Use						
EPO Dose (1000 IUs)	62.89	61.34	61.77	55.37	52.01	58.69
Receives Any EPO	0.813	0.802	0.795	0.732	0.713	0.771
Medicare Spending ($)						
Total	8,016	7,999	7,305	7,299	6,801	7,483
Inpatient	2,846	2,818	2,492	2,520	2,320	2,599
Dialysis	2,283	2,326	2,236	2,211	2,145	2,240
Part D	442	445	417	394	382	416
Outpatient	332	364	377	387	361	364
Health Outcomes						
Hemoglobin (g/dL)	11.46	11.45	11.44	11.45	11.46	11.45
Mortality	0.016	0.016	0.017	0.018	0.017	0.017
Hospitalizations						
Any Cause	0.1471	0.1446	0.1420	0.1463	0.1391	0.1438
Cardiac Event	0.0307	0.0303	0.0289	0.0300	0.0267	0.0293
Septicemia	0.0093	0.0091	0.0088	0.0089	0.0084	0.0089
Transfusions						
Total	0.0256	0.0249	0.0247	0.0256	0.0244	0.0250
Inpatient	0.0219	0.0211	0.0201	0.0203	0.0188	0.0205
Outpatient	0.0042	0.0042	0.0051	0.0059	0.0063	0.0051
Emergency Room	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Unique Patients	54,576	52,150	54,661	53,701	54,001	256,504
Patient-Months	477,695	457,844	478,139	467,866	468,898	2,350,442

Notes: An observation is a patient-month. Sample consists of observations from January to December 2009 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Predicted mortality is the predicted value for each observation from a regression of mortality on patient controls and time fixed effects. Time fixed effects are not included in the prediction. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. Facility elevation is measured in feet above sea level. The cut points between elevation quintiles are 73, 260, 599, and 870 feet above sea level.

Table A3
Patient Descriptive Statistics by Elevation, 2012

	Elevation Quintile					
	First	Second	Third	Fourth	Fifth	Total
Patient Characteristics						
Predicted Mortality	0.015	0.015	0.015	0.016	0.016	0.016
Age (Years)	63.37	63.63	62.85	63.35	63.33	63.31
Months with ESRD	48.98	48.68	49.02	48.59	46.44	48.34
Black	0.448	0.443	0.454	0.379	0.213	0.388
Male	0.556	0.551	0.546	0.554	0.565	0.554
Diabetic	0.538	0.542	0.546	0.555	0.569	0.550
Hypertensive	0.911	0.908	0.909	0.906	0.902	0.907
Incident Hemoglobin	9.664	9.710	9.737	9.819	9.935	9.772
Facility Characteristics						
Facility Elevation (ft)	29.2	144.3	434.4	713.6	1886.7	637.2
Independent Ownership	0.172	0.161	0.150	0.197	0.184	0.173
Resource Use						
EPO Dose (1000 IUs)	36.65	36.05	36.67	34.20	30.38	34.81
Receives Any EPO	0.759	0.761	0.751	0.708	0.662	0.728
Medicare Spending ($)						
Total	7,884	7,890	7,224	7,290	6,959	7,453
Inpatient	2,637	2,564	2,277	2,301	2,196	2,397
Dialysis	2,390	2,456	2,334	2,353	2,322	2,371
Part D	571	550	523	499	480	525
Outpatient	373	417	441	463	427	424
Health Outcomes						
Hemoglobin (g/dL)	10.79	10.81	10.82	10.83	10.89	10.83
Mortality	0.015	0.014	0.015	0.015	0.015	0.015
Hospitalizations						
Any Cause	0.1344	0.1305	0.1283	0.1348	0.1275	0.1311
Cardiac Event	0.0257	0.0258	0.0246	0.0256	0.0227	0.0249
Septicemia	0.0103	0.0100	0.0094	0.0099	0.0094	0.0098
Transfusions						
Total	0.0326	0.0302	0.0296	0.0298	0.0288	0.0302
Inpatient	0.0279	0.0257	0.0236	0.0234	0.0221	0.0246
Outpatient	0.0053	0.0051	0.0067	0.0072	0.0075	0.0064
Emergency Room	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Unique Patients	60,055	58,219	58,652	58,026	58,970	280,751
Patient-Months	543,541	528,788	531,440	518,537	527,525	2,649,831

Notes: An observation is a patient-month. Sample consists of observations from January to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Predicted mortality is the predicted value for each observation from a regression of mortality on patient controls and time fixed effects. Time fixed effects are not included in the prediction. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. Facility elevation is measured in feet above sea level. The cut points between elevation quintiles are 73, 260, 599, and 870 feet above sea level.

C. Potential Anticipatory Responses

Given the difficulty of changing clinical practices, we may expect them to change gradually and in anticipation of the bundle. Indeed, in Figures 1 and 4, among others, we see that EPO doses began to decrease in mid-2010, prior to the bundle's start in January 2011. In this appendix, we both quantify these anticipatory effects as well as show that our results are robust to changing the date of treatment to include this period of anticipatory responses by providers.

To identify and quantify a possible anticipation, we use the methods of Brot-Goldberg et al. (2017). First, we estimate

$$\bar{Y}_t = \beta_0 + \beta_1 t + X_t + \bar{\epsilon}_t, \tag{9}$$

where $\bar{Y}_t$ is the mean EPO dose in month t and X_t is a series of month fixed effects. We estimate this equation using only data from January 2005 through December 2009 and then use the estimated coefficients to calculate the predicted level of EPO for each month in 2010 and 2011. From the predicted and observed values values in Table A4, we find that the first month in which the realized mean EPO dose is below the predicted level is October 2010, and that this drop continues to grow through 2011.

We corroborate our finding that the anticipatory response began in October 2010 by using a falsification test from Baicker and Svoronos (2019). To do so, we construct a test statistic from a series of Wald tests, testing each month in our data as a potential structural break in the time series of mean monthly EPO doses. From this, October 2010 returns the highest Wald statistic, 269, suggesting it is the most likely month of a structural break in the trend in EPO doses, which would indicate an anticipation of the bundle by providers.

In light of a possible anticipatory response, we consider the robustness of our main findings to this anticipation. In particular, we recreate the tables and figures presented in the main text treating the start date of the bundle as October 2010 rather than the actual start date of January 2011. In this way, we treat the period during which facilities were modifying behavior in anticipation of the bundle as part of the treatment period. Tables A5–A9 and Figure A3 recreate our main results and show that they are robust to this alternative definition of the bundle period.

Table A4
Difference in EPO Relative to Trend

	Actual	Predicted	Difference
2010			
January	58.58	55.86	2.72
February	55.55	52.04	3.52
March	62.88	57.53	5.36
April	59.01	55.64	3.37
May	58.26	57.70	0.56
June	58.68	56.26	2.41
July	59.22	57.27	1.95
August	57.39	57.39	0.01
September	55.43	55.43	0.00
October	53.25	57.21	-3.96
November	51.56	54.70	-3.14
December	50.53	56.55	-6.02
2011			
January	49.78	54.33	-4.55
February	45.79	50.50	-4.72
March	50.56	55.99	-5.44
April	48.70	54.11	-5.40
May	48.19	56.17	-7.98
June	47.64	54.73	-7.09
July	46.58	55.74	-9.16
August	42.81	55.85	-13.04
September	38.56	53.90	-15.34
October	38.92	55.67	-16.76
November	38.59	53.17	-14.58
December	38.55	55.02	-16.47

Notes: Predicted values from OLS estimate of equation 9. Dependent variable is monthly EPO dose. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. An observation is a patient-month. Estimation sample consists of observations from January 2005 to December 2009 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Sample presented in table consist of analogous observations from January 2010 to December 2011.

Table A5
Effect of Bundle on EPO Dose

	(1) EPO	(2) EPO	(3) EPO	(4) EPO
PPS	-19.19***	-20.82***	-17.91***	-5.035***
	(0.243)	(0.233)	(0.417)	(0.223)
Pat/Fac Controls	0	1	1	1
Facility FE	0	0	1	1
Patient FE	0	0	0	1
Dep. Var. Mean	46.82	46.82	46.82	46.86
R-squared	0.0240	0.0812	0.136	0.532
Observations	10157714	10157714	10157683	10139936

Notes: OLS estimates from equation (1). Dependent variable is monthly EPO dose. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. PPS is an indicator variable for October 2010 or later. An observation is a patient-month. Sample consists of observations from October 2008 to September 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

Table A6
Effect of Bundle on Health Outcomes

	(1) HGB	(2) Transfusion	(3) Hosp., Any Cause	(4) Hosp., Cardiac Event	(5) Mortality
PPS	-0.442***	0.00499***	-0.00560***	-0.00211***	-0.000829***
	(0.00815)	(0.000208)	(0.000452)	(0.000187)	(0.000116)
Pat/Fac Controls	1	1	1	1	1
Facility FE	1	1	1	1	1
Dep. Var. Mean	11.08	0.0287	0.137	0.0267	0.0156
R-squared	0.0758	0.0118	0.0212	0.00775	0.00843
Observations	8304637	10157683	10157683	10157683	10157683

Notes: OLS estimates from equation (2). Dependent variable in column (1) is hemoglobin. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. Dependent variables in columns (2)–(5) are binary outcome variables. PPS is an indicator variable for October 2010 or later. An observation is a patient-month. Sample consists of observations from October 2008 to September 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

Table A7
The Effect of EPO on Health Outcomes

	HGB		Transfusion	
	(1) OLS	(2) IV	(3) OLS	(4) IV
EPO	-0.00287***	0.0165***	0.000127***	-0.000580***
	(0.0000252)	(0.00465)	(0.00000252)	(0.000149)
Year-Month FE	1	1	1	1
Pat/Fac Controls	1	1	1	1
Facility FE	1	1	1	1
Dep. Var. Mean	11.17	11.17	0.0279	0.0279
Observations	8056164	8056164	9979284	9979284
First-Stage F-statistic		37.28		54.89

Notes: OLS and IV estimates from equation (3). Dependent variable in columns (1)–(2) is hemoglobin. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. Dependent variables in columns (3)–(4) is a binary outcome variable for receiving a blood transfusion. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. An observation is a patient-month. Sample consists of observations from October 2008 to September 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

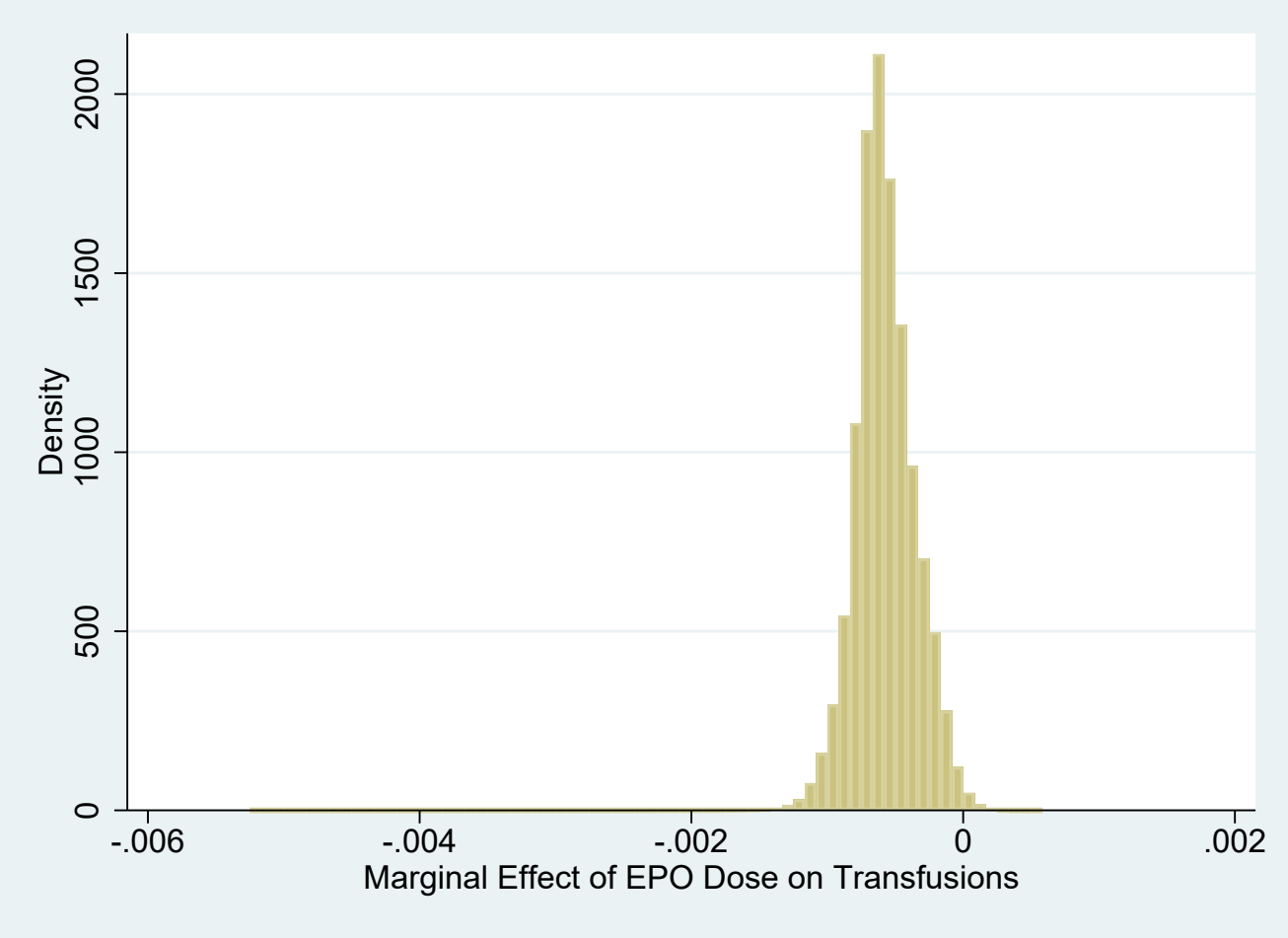
Table A8
The Effect of EPO on Hospitalizations and Mortality

	Hosp., Any Cause		Hosp., Cardiac Event		Hosp., Septicemia		Mortality	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
EPO	0.000157***	0.0000821	0.0000160***	0.000123	-0.000000428	0.0000280	-0.000115***	0.000147*
	(0.00000351)	(0.000242)	(0.00000122)	(0.0000976)	(0.000000602)	(0.0000534)	(0.000000888)	(0.0000659)
Year-Month FE	1	1	1	1	1	1	1	1
Pat/Fac Controls	1	1	1	1	1	1	1	1
Facility FE	1	1	1	1	1	1	1	1
Dep. Var. Mean	0.139	0.139	0.0274	0.0274	0.00930	0.00930	0.0159	0.0159
Observations	9979284	9979284	9979284	9979284	9979284	9979284	9979284	9979284
First-Stage F-statistic		54.89		54.89		54.89		54.89

Notes: OLS and IV estimates from equation (3). Dependent variables are binary outcomes. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. An observation is a patient-month. Sample consists of observations from October 2008 to September 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

Figure A3

Histogram of Predicted Marginal Effects ($\widehat{\frac{\partial Y_{ijt}}{\partial E_{ijt}}}$) of EPO on Transfusions



Notes: Predicted values come from IV estimates of equation (6). An observation is a patient-month. Sample consists of observations from October 2008 to September 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs.

Table A9

Difference in EPO by the Responsiveness of Transfusions to EPO

	(1) EPO	(2) EPO	(3) Transfusion	(4) Transfusion	(5) Mortality	(6) Mortality
EPO-Responsiveness Z-Score	-1.130***	-1.075***	-0.00985***	-0.00981***	-0.00801***	-0.00801***
	(0.103)	(0.102)	(0.000169)	(0.000168)	(0.000107)	(0.000107)
PPS	-5.748***		0.00300***		-0.000278	
	(0.238)		(0.000287)		(0.000178)	
EPO-Responsiveness Z-Score × PPS	1.394***	1.289***	0.00437***	0.00430***	0.00433***	0.00434***
	(0.104)	(0.103)	(0.000182)	(0.000183)	(0.000109)	(0.000110)
Time Trend	-0.595***		-0.00000308		-0.0000912***	
	(0.0139)		(0.0000122)		(0.00000763)	
Facility Controls	1	1	1	1	1	1
Facility FE	1	1	1	1	1	1
Month FE and Trend	1	0	1	0	1	0
Year-Month FE	0	1	0	1	0	1
R-squared	0.124	0.125	0.00926	0.00933	0.00471	0.00472
Dep. Var. Mean	46.82	46.82	0.0287	0.0287	0.0156	0.0156
Observations	10157683	10157683	10157683	10157683	10157683	10157683

Notes: OLS estimates from equation (8). Dependent variable in columns (1)–(2) is monthly EPO dose. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. Dependent variables in columns (3)–(6) are binary outcome variables. PPS is an indicator variable for October 2010 or later. Time Trend is a continuous measure of months since October 2010. This means the value for October 2010 is zero, while it is positive for subsequent months and negative for prior months. Post-PPS Trend Change is the interaction of PPS and Time Trend. Estimated MFX Z-Score is the standardized patient-level estimated marginal effect predicted using the IV estimates of 6. An observation is a patient-month. Sample consists of observations from October 2008 to September 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

Table A10
Difference in EPO by Responsiveness of Transfusions to EPO and Chain Status

	(1) EPO	(2) EPO	(3) Transfusion	(4) Transfusion	(5) Mortality	(6) Mortality
Chain Ownership	11.50***	11.81***	-0.00237*	-0.00175+	-0.000425	-0.000286
	(1.633)	(1.610)	(0.00102)	(0.000954)	(0.000487)	(0.000443)
EPO-Responsiveness	-0.463**	-1.163***	-0.0103***	-0.0103***	-0.00768***	-0.00771***
Z-Score	(0.169)	(0.172)	(0.000375)	(0.000369)	(0.000259)	(0.000252)
EPO-Responsiveness	-0.830***	0.115	0.000570	0.000634	-0.000422	-0.000391
Z-Score × Chain	(0.208)	(0.209)	(0.000418)	(0.000411)	(0.000283)	(0.000275)
PPS	-1.407*		0.00213**		-0.000359	
	(0.574)		(0.000662)		(0.000387)	
PPS × Chain	-5.372***		0.00108		0.0000964	
	(0.599)		(0.000707)		(0.000418)	
EPO-Responsiveness	0.532*	0.578*	0.00441***	0.00434***	0.00397***	0.00398***
Z-Score × PPS	(0.219)	(0.232)	(0.000405)	(0.000403)	(0.000241)	(0.000240)
EPO-Responsiveness	1.064***	0.867***	-0.0000749	-0.0000846	0.000463+	0.000459+
Z-Score × PPS × Chain	(0.247)	(0.258)	(0.000453)	(0.000450)	(0.000269)	(0.000267)
Time Trend	-0.358***		0.0000518*		-0.0000769***	
	(0.0248)		(0.0000259)		(0.0000159)	
Time Trend × Chain	-0.288***		-0.0000664*		-0.0000177	
	(0.0243)		(0.0000273)		(0.0000166)	
Facility Controls	1	1	1	1	1	1
Facility FE	1	1	1	1	1	1
Month FE and Trend	1	0	1	0	1	0
Year-Month FE	0	1	0	1	0	1
R-squared	0.125	0.125	0.00927	0.00933	0.00471	0.00472
Dep. Var. Mean	46.82	46.82	0.0287	0.0287	0.0156	0.0156
Observations	10157683	10157683	10157683	10157683	10157683	10157683

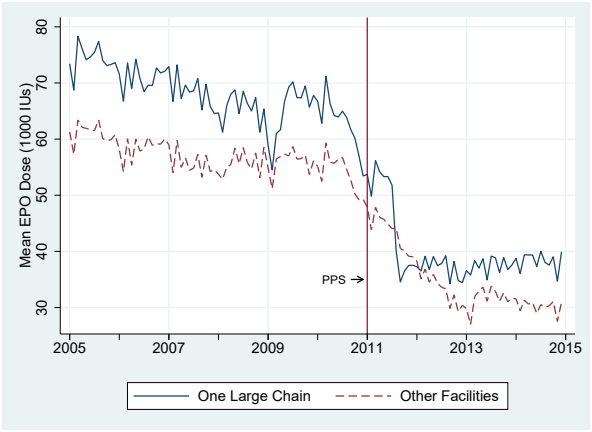
Notes: OLS estimates from equation (8) with additional interactions with an indicator for chain ownership. Dependent variable in columns (1)–(2) is monthly EPO dose. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. Dependent variables in columns (3)–(6) are binary outcome measures. PPS is an indicator variable for October 2010 or later. Time Trend is a continuous measure of months since October 2010. This means the value for October 2010 is zero, while it is positive for subsequent months and negative for prior months. Post-PPS Trend Change is the interaction of PPS and Time Trend. Estimated MFX Z-Score is the standardized patient-level estimated marginal effect predicted using the IV estimates of 6. An observation is a patient-month. Sample consists of observations from October 2008 to September 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. +, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

D. Amgen Sourcing and Supply Agreements

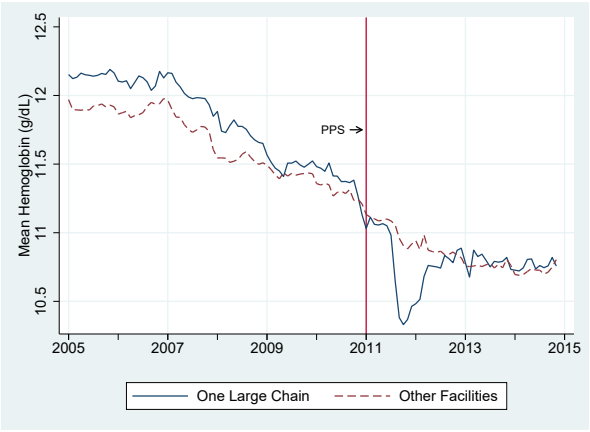
The large dialysis chains DaVita and Fresenius have at times partnered with Amgen, a leading producer of ESAs, to make administering drugs such as EPO more profitable. In 2011, DaVita entered into a sourcing and supply agreement with Amgen, providing DaVita with discounts and rebates for Amgen's two ESAs, EPOGEN and Aranesp (DaVita Amgen Agreement 2011). In return, DaVita agreed to purchase at least 90% of its ESAs from Amgen. This 2011 contract ran through 2018 and was renewed in 2017 to extend through 2022 (DaVita Amgen Agreement 2017). Fresenius entered into a similar sourcing and supply agreement with Amgen in 2006, extending to 2011 (Fresenius Amgen Agreement 2006). Fresenius' contract lacked minimum purchase commitments, but did secure discounts for EPOGEN and Aranesp. Following this, Fresenius now has year-to-year contracts with Amgen.

We notice a distinct drop in hemoglobin in mid-2011. As discussed in Appendix A, this corresponds to the second FDA black box warning and the removal of the percentage of patients with HGB below 10 g/dL as a QIP measure. Furthermore, it also corresponds to the renegotiation of multiple large chains' contracts with Amgen, the monopoly supplier of EPO at the time. We see that the sharp drop in EPO and hemoglobin levels occurs only for patients of one of these large chains. This gives further evidence that the cause of the drop in EPO and hemoglobin is likely not the FDA black box warning but rather the renegotiation of this chain's supply agreement with Amgen. Because the contract renegotiation occurred at the same time as the bundled payment reform, the renegotiation likely reflects changing provider strategy following the bundle. If this is the case, then the drop in EPO and hemoglobin occurring in mid-2011 would be attributable to the bundle, with the delay highlighting the sticky nature of chains' supply agreements.

Figure A4
EPO Doses and HGB by Facility Ownership



(a) Monthly EPO Dose for One Large Chain and Other Facilities' Patients



(b) Mean HGB for One Large Chain and Other Facilities' Patients

Notes: An observation is a patient-month. Sample consists of observations from January 2005 to December 2014 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. The vertical line indicates the start of PPS in January 2011.

E. Additional Time Series Results

Table A11
Effect of Bundle on Medicare Spending

	Medicare Spending				
	(1) Inpatient	(2) Outpatient	(3) Part D	(4) Dialysis	(5) Total
PPS	-83.23***	31.38***	53.61***	68.81***	-19.78
	(11.16)	(2.211)	(1.923)	(4.234)	(15.63)
Pat/Fac Controls	1	1	1	1	1
Facility FE	1	1	1	1	1
Dep. Var. Mean	2557.5	393.7	465.2	2286.8	7555.4
R-squared	0.0133	0.0168	0.0700	0.0819	0.0309
Observations	9771287	9771287	9771287	9771287	9771287

Notes: OLS estimates from equation (2). Dependent variables are components of Medicare spending, denominated in dollars. PPS is an indicator variable for January 2011 or later. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

Table A12
Effect of Bundle on EPO and Outcomes, Pre- and Post-Trends

	(1) EPO	(2) HGB	(3) Transfusion	(4) Hosp., Any Cause	(5) Hosp., Cardiac Event	(6) Mortality
PPS	-6.671***	-0.231***	0.00481***	0.000582	0.0000238	0.0000603
	(0.273)	(0.00645)	(0.000289)	(0.000626)	(0.000266)	(0.000181)
Time Trend	-0.187***	-0.00935***	0.0000707***	-0.000173***	-0.0000868***	-0.0000397***
	(0.0187)	(0.000354)	(0.0000155)	(0.0000373)	(0.0000157)	(0.0000103)
Post-PPS Trend Change	-0.681***	-0.00271***	-0.0000868***	-0.000240***	-0.0000317^{+}	-0.0000104
	(0.0212)	(0.000420)	(0.0000209)	(0.0000467)	(0.0000192)	(0.0000120)
Pat/Fac Controls	1	1	1	1	1	1
Facility FE	1	1	1	1	1	1
Dep. Var. Mean	48.27	11.12	0.0282	0.138	0.0272	0.0157
R-squared	0.139	0.0772	0.0118	0.0189	0.00722	0.00850
Observations	10077264	8181736	10077264	8869206	8869206	10077264

Notes: OLS estimates from equation (2). Dependent variable in column (1) is monthly EPO dose. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. Dependent variable in column (2) is hemoglobin. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. Dependent variables in columns (3)–(6) are binary outcome variables. PPS is an indicator variable for January 2011 or later. Time Trend is a continuous measure of months since January 2011. This means the value for January 2011 is zero, while it is positive for subsequent months and negative for prior months. Post-PPS Trend Change is the interaction of PPS and Time Trend. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

Table A13
Effect of Bundle on Medicare Spending, Pre- and Post-Trends

	Medicare Spending				
	(1) Inpatient	(2) Outpatient	(3) Part D	(4) Dialysis	(5) Total
PPS	19.89	-4.899*	12.07***	8.641*	-9.478
	(15.71)	(2.178)	(1.498)	(3.991)	(20.03)
Time Trend	2.399**	1.848***	1.232***	0.427+	10.62***
	(0.896)	(0.132)	(0.102)	(0.223)	(1.195)
Post-PPS Trend Change	-16.06***	0.0220	1.873***	5.553***	-23.30***
	(1.133)	(0.166)	(0.145)	(0.256)	(1.528)
Pat/Fac Controls	1	1	1	1	1
Facility FE	1	1	1	1	1
Dep. Var. Mean	2557.5	393.7	465.2	2286.8	7555.4
R-squared	0.0133	0.0168	0.0703	0.0827	0.0309
Observations	9771287	9771287	9771287	9771287	9771287

Notes: OLS estimates from equation (2). Dependent variables are components of Medicare spending, denominated in dollars. PPS is an indicator variable for January 2011 or later. Time Trend is a continuous measure of months since January 2011. This means the value for January 2011 is zero, while it is positive for subsequent months and negative for prior months. Post-PPS Trend Change is the interaction of PPS and Time Trend. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

F. Allocative Efficiency of Improving HGB Levels

In this section, we repeat the exercise from Section 5 using equation (6) to estimate heterogeneity in the effect of EPO on patients' end-of-month HGB levels. HGB is a direct measure of anemia severity and a key component of the mechanism through which EPO affects patient outcomes, including the need for blood transfusions. We construct each patient's EPO-responsiveness Z-score in a similar manner as before, the one difference here being that we do not multiply by -1, as the distribution of marginal effects of EPO on HGB is already positive. We classify patients for whom EPO is effective at raising HGB as "EPO-responsive."

It is natural to expect individuals who are responsive to EPO in the sense that it increases their HGB to be the same individuals for whom EPO decreases the likelihood that they need a transfusion, but this need not be true. We find that the correlation between these two notions of responsiveness is 0.2641. Appendix Table A14 gives the number of patient-month observations in the quintiles of the estimated marginal effect of EPO on hemoglobin and transfusion rates. It generally shows that patients in the low or high end of the distribution of HGB-responsiveness are found in the same end of the distribution of transfusion-responsiveness.

Figure A6 breaks out time trends in EPO doses and HGB levels by EPO-responsiveness type with respect to HGB levels. The figure shows that for EPO-unresponsive patients, doses fell relatively more than for EPO-responsive patients, similar to what we saw with the marginal effects on transfusions. Panel (b) shows this is driven at least in part by the extensive margin, with patients who are unresponsive to EPO taken off the drug altogether, suggesting a reduction in waste. Looking at trends in HGB levels in Figure A6, we see an overall decrease in HGB levels, but this decrease is greater for EPO-responsive patients (those who see the smallest drop in their EPO doses).

Figure A6 also shows a pronounced drop and recovery of HGB levels for EPO-unresponsive patients. In January 2012, the reporting requirements for hemoglobin levels changed. Prior to this date, hemoglobin only had to be reported on claims for reimbursement of EPO; after, all claims were required to report hemoglobin. This means that prior to 2012, we only observe HGB levels for those patients who also receive EPO. To reduce concerns that the differential change in EPO we estimate for patients based on the responsiveness of their HGB to EPO doses is driven by this reporting change, we recreate panel (d) of Figure A6 using only those observations for which the EPO dose is strictly positive. This

Table A14
Crosstabulation of EPO-Responsiveness with Respect to EPO and to Transfusion Rates

	EPO Sensitivity of Transfusions, Quintiles					
EPO Sensitivity of HGB	First	Second	Third	Fourth	Fifth	Total
First Quintile	498,053	493,162	423,011	340,668	260,591	2,015,485
Second Quintile	494,449	437,545	424,188	367,088	292,171	2,015,441
Third Quintile	416,823	412,358	424,942	429,506	331,822	2,015,451
Fourth Quintile	373,208	384,623	411,057	442,250	404,363	2,015,501
Fifth Quintile	232,928	287,790	332,279	435,937	726,477	2,015,411
Total	2,015,461	2,015,478	2,015,477	2,015,449	2,015,424	10,077,289

Notes: An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Quintiles along the vertical axis were determined by within-patient average estimated marginal effect of EPO on hemoglobin from IV estimates of 6. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. Quintiles along the horizontal axis were similarly determined with a binary measure of transfusions as the dependent variable of 6.

means that we restrict our attention to only those observations for which EPO was required to be reported both before and after the change in reporting requirements. We see in Figure A7 that, while the differences between EPO-responsive and EPO-unresponsive patients are more muted, we nonetheless see the same pattern.

Results from estimating equation (8) are displayed in Table A16 and echo the results using transfusions. Prior to the bundle, EPO-responsive patients received lower doses than unresponsive patients did. This is in line with the incentive structure of the pre-2011 era for providers seeking to maximize profits while respecting clinical standards. As discussed in Section 2, clinical guidelines at the time directed providers to avoid treating patients with HGB levels over 12 g/dL. EPO-unresponsive patients provided an opportunity to increase revenues through large EPO doses with little risk of HGB levels exceeding this threshold. The results in column (1) indicate that a patient with an estimated marginal effect of EPO on hemoglobin one standard deviation below the mean received 1408 more units of EPO than a patient with similar observable characteristics who has an average EPO-responsiveness. While the level of EPO decreased for all types of patients, the difference between EPO-responsive and EPO-unresponsive patients shrunk, indicating that EPO decreased more for the EPO-unresponsive patients. We also see that the EPO-responsive patients had higher levels of hemoglobin than the EPO-unresponsive did prior to the bundle. After the bundle, the HGB levels of both types of patients decreased, but more so for the EPO-unresponsive types, suggesting a reallocation from low-return to higher-return patients.

Table A15

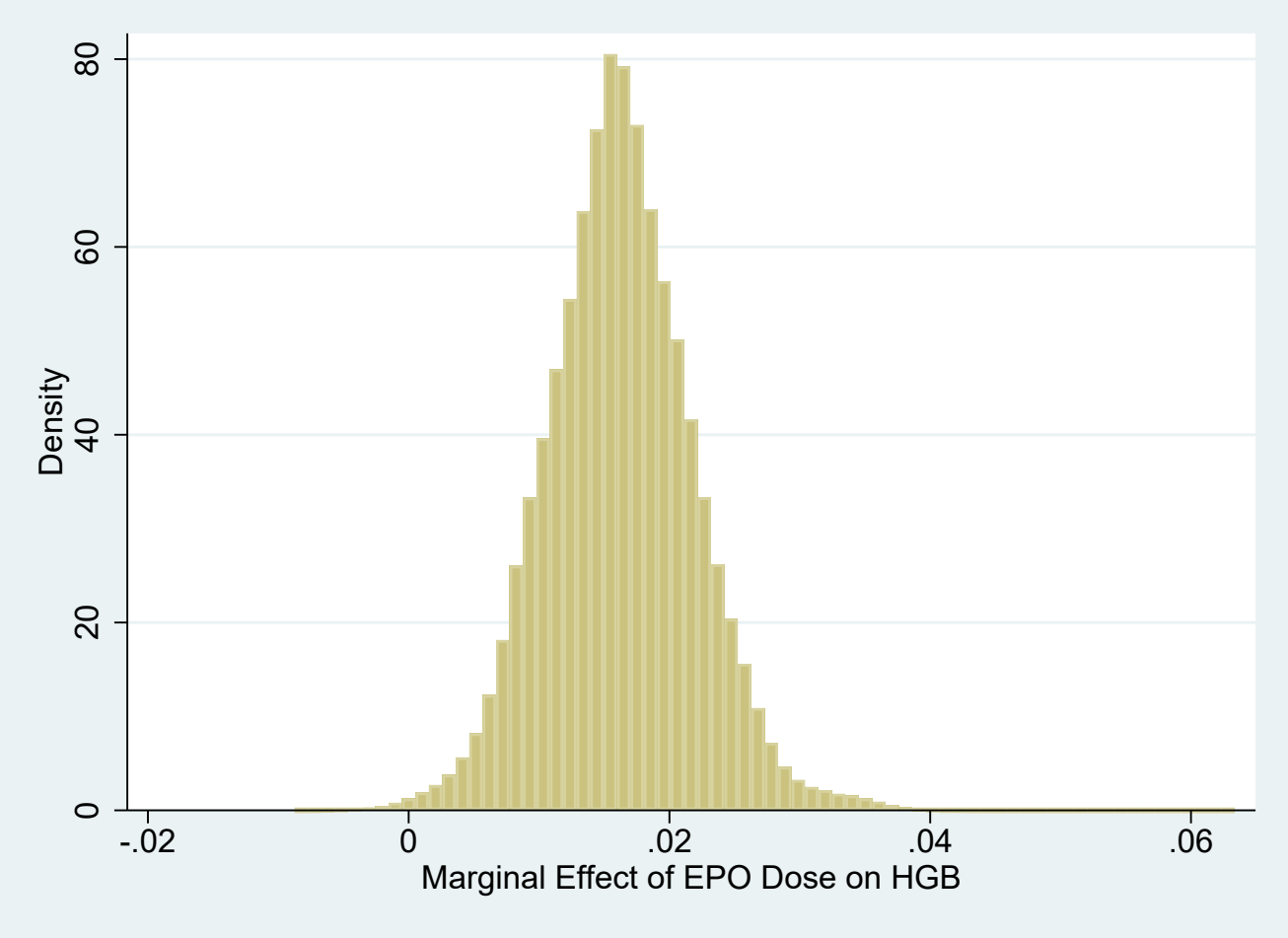
Patient Descriptive Statistics by the Responsiveness of Hemoglobin to EPO

	EPO-Responsiveness Quintile				
	First	Second	Third	Fourth	Fifth
Patient Characteristics					
Marginal Effect of EPO	0.009	0.013	0.016	0.019	0.024
Predicted Mortality	0.012	0.014	0.014	0.018	0.020
Age (Years)	54.71	58.77	61.52	67.98	72.63
Months with ESRD	58.55	44.68	37.93	36.10	34.20
Black	0.401	0.377	0.413	0.367	0.355
Male	0.879	0.703	0.610	0.452	0.170
Diabetic	0.444	0.511	0.541	0.558	0.573
Hypertensive	0.930	0.914	0.903	0.893	0.890
Incident Hemoglobin	10.500	9.895	9.741	9.768	9.768
Facility Characteristics					
Facility Elevation (ft)	669.9	663.6	644.7	635.4	585.1
Independent Ownership	0.218	0.221	0.214	0.219	0.220
Resource Use					
EPO Dose (1000 IUs)	59.66	60.68	60.09	57.98	55.59
Receives Any EPO	0.718	0.752	0.774	0.789	0.813
Medicare Spending ($)					
Total	7,381	7,572	7,509	7,494	7,463
Inpatient	2,540	2,690	2,649	2,598	2,527
Dialysis	2,384	2,285	2,228	2,190	2,138
Part D	487	444	412	370	378
Outpatient	365	376	368	365	349
Health Outcomes					
Hemoglobin (g/dL)	11.45	11.44	11.45	11.45	11.46
Mortality	0.014	0.016	0.016	0.018	0.019
Hospitalizations					
Any Cause	0.1339	0.1438	0.1460	0.1467	0.1477
Cardiac Event	0.0255	0.0274	0.0292	0.0308	0.0332
Septicemia	0.0081	0.0087	0.0087	0.0094	0.0093
Transfusions					
Total	0.0213	0.0247	0.0258	0.0267	0.0263
Inpatient	0.0169	0.0200	0.0210	0.0219	0.0221
Outpatient	0.0049	0.0053	0.0054	0.0054	0.0047
Emergency Room	0.0001	0.0001	0.0001	0.0001	0.0001
Unique Patients	48,745	49,243	50,429	53,170	54,917
Patient-Months	444,269	441,125	459,997	490,934	514,117

Notes: An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Predicted mortality is the predicted value for each observation from a regression of mortality on patient controls and time fixed effects. Time fixed effects are not included in the prediction. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. Facility elevation is measured in feet above sea level. Predicted values come from IV estimates of equation (6) with hemoglobin as the dependent variable.

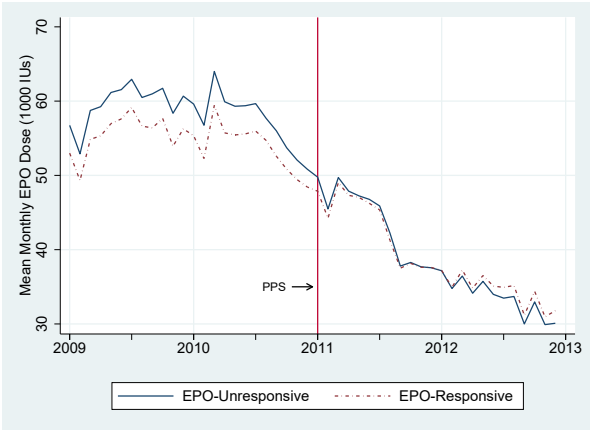
Figure A5

Histogram of Predicted Marginal Effects ($\widehat{\frac{\partial Y_{ijt}}{\partial E_{ijt}}}$) of EPO on Hemoglobin



Notes: Predicted values come from IV estimates of equation (6) with hemoglobin as the dependent variable. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter.

Figure A6
EPO Dosing and HGB Levels Over Time by Responsiveness of Hemoglobin to EPO



(a) Monthly EPO Dose Over Time by EPO Responsiveness

(b) Hemoglobin Over Time by EPO Responsiveness

Notes: "EPO-responsive" ("EPO-unresponsive") refers to patients with average estimated marginal effects of EPO on hemoglobin in the fifth (first) quintile. This corresponds to being at least 0.79 standard deviations above (0.81 standard deviations below) the average estimated marginal effect. Predicted values come from IV estimates of 6 with hemoglobin as the dependent variable. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. The vertical line indicates the start of PPS in January 2011.

Figure A7
Hemoglobin Levels Over Time by EPO Responsiveness, Including Only Observations with a Positive EPO Dose

Notes: "EPO-responsive" ("EPO-unresponsive") refers to patients with average estimated marginal effects of EPO on hemoglobin in the fifth (first) quintile. This corresponds to being at least 0.79 standard deviations above (0.81 standard deviations below) the average estimated marginal effect. Predicted values come from IV estimates of 6 with hemoglobin as the dependent variable. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. The sample included in the figure is further limited to those receiving a strictly positive EPO dose. The vertical line indicates the start of PPS in January 2011.

Table A16
Difference in EPO by the Responsiveness of Hemoglobin to EPO

	(1) EPO	(2) EPO	(3) HGB	(4) HGB	(5) Mortality	(6) Mortality
EPO-Responsiveness Z-Score	-1.408***	-1.364***	0.00376**	0.00397**	0.00162***	0.00162***
	(0.102)	(0.102)	(0.00125)	(0.00126)	(0.0000615)	(0.0000615)
PPS	-6.144***		-0.224***		0.0000508	
	(0.272)		(0.00652)		(0.000182)	
EPO-Responsiveness Z-Score × PPS	1.602***	1.495***	-0.0786***	-0.0782***	0.000245**	0.000243**
	(0.0989)	(0.0989)	(0.00184)	(0.00185)	(0.0000791)	(0.0000790)
Time Trend	-0.516***		-0.0110***		-0.0000389***	
	(0.0145)		(0.000329)		(0.00000801)	
Facility Controls	1	1	1	1	1	1
Facility FE	1	1	1	1	1	1
Month FE and Trend	1	0	1	0	1	0
Year-Month FE	0	1	0	1	0	1
R-squared	0.123	0.125	0.0729	0.0763	0.00276	0.00277
Dep. Var. Mean	48.27	48.27	11.12	11.12	0.0157	0.0157
Observations	10077264	10077264	8181736	8181736	10077264	10077264

Notes: OLS estimates from 8. The dependent variable in columns (1)–(2) is monthly EPO dose. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. The dependent variable in columns (3)–(4) is hemoglobin. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. PPS is an indicator variable for January 2011 or later. Time Trend is a continuous measure of months since January 2011. This means the value for January 2011 is zero, while it is positive for subsequent months and negative for prior months. Post-PPS Trend Change is the interaction of PPS and Time Trend. Estimated MFX Z-Score is the standardized patient-level estimated marginal effect predicted using the IV estimates of 6 with hemoglobin as the dependent variable. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

Table A17

Difference in EPO by the Responsiveness of Hemoglobin to EPO and Chain Status

	(1) EPO	(2) EPO	(3) HGB	(4) HGB	(5) Mortality	(6) Mortality
Chain Ownership	10.30***	10.98***	0.0171	0.000579	-0.000250	0.000105
	(1.764)	(1.768)	(0.0244)	(0.0215)	(0.000483)	(0.000436)
EPO-Responsiveness	-0.917***	-1.082***	0.00301	0.00266	0.00143***	0.00142***
Z-Score	(0.186)	(0.181)	(0.00346)	(0.00352)	(0.000134)	(0.000134)
EPO-Responsiveness	-0.617**	-0.361+	0.000966	0.00164	0.000241	0.000250+
Z-Score × Chain	(0.220)	(0.216)	(0.00369)	(0.00377)	(0.000150)	(0.000151)
PPS	-2.699***		-0.201***		-0.000362	
	(0.715)		(0.0213)		(0.000377)	
PPS × Chain	-4.265***		-0.0298		0.000513	
	(0.748)		(0.0222)		(0.000408)	
EPO-Responsiveness	0.350	0.322	-0.0608***	-0.0600***	0.000294	0.000293
Z-Score × PPS	(0.235)	(0.227)	(0.00513)	(0.00520)	(0.000181)	(0.000181)
EPO-Responsiveness	1.535***	1.454***	-0.0216***	-0.0222***	-0.0000706	-0.0000705
Z-Score × PPS × Chain	(0.259)	(0.253)	(0.00547)	(0.00553)	(0.000201)	(0.000201)
Time Trend	-0.288***		-0.0114***		-0.0000123	
	(0.0252)		(0.000835)		(0.0000153)	
Time Trend × Chain	-0.280***		0.000590		-0.0000333*	
	(0.0239)		(0.000809)		(0.0000157)	
Facility Controls	1	1	1	1	1	1
Facility FE	1	1	1	1	1	1
Month FE and Trend	1	0	1	0	1	0
Year-Month FE	0	1	0	1	0	1
R-squared	0.124	0.125	0.0729	0.0763	0.00276	0.00277
Dep. Var. Mean	48.27	48.27	11.12	11.12	0.0157	0.0157
Observations	10077264	10077264	8181736	8181736	10077264	10077264

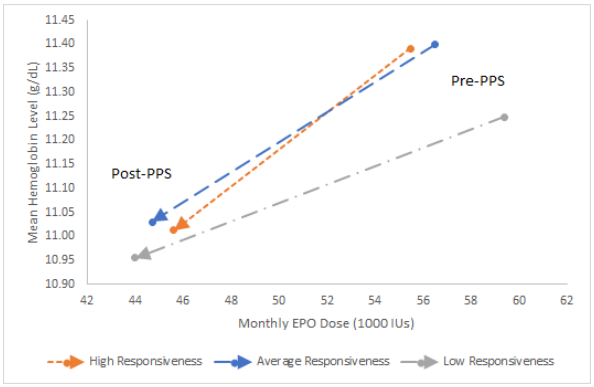
Notes: OLS estimates from equation (8). Dependent variable in columns (1)–(2) is monthly EPO dose. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. Dependent variable in columns (3)–(4) is hemoglobin. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. PPS is an indicator variable for January 2011 or later. Time Trend is a continuous measure of months since January 2011. This means the value for January 2011 is zero, while it is positive for subsequent months and negative for prior months. Post-PPS Trend Change is the interaction of PPS and Time Trend. Estimated MFX Z-Score is the standardized patient-level estimated marginal effect predicted using the IV estimates of 6 with hemoglobin as the dependent variable. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

G. Supplemental Tables and Figures from Section 5

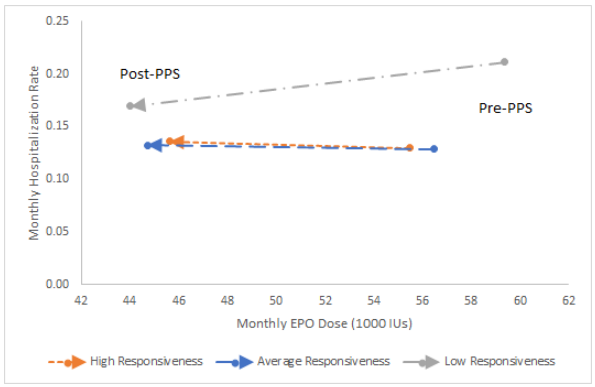
Tables A18 and A19 present OLS estimates from equation (8) with various dependent variables that were not presented in Section 5. Tables A20–A22 present estimates of an equation similar to equation (8) that replaces the linear term for the Z-score of the estimated marginal effects, $z_{\widehat{\frac{\partial Y_{ijt}}{\partial E_{ijt}}}}$, with a series of indicator variables for the associated EPO-responsiveness quintile. We view this specification to be less parametric than the linear version, though somewhat more cumbersome to interpret. To aid with interpretation, we plot model predictions in Figures A8 and A9. Like Figure 7 in the body of the paper, these plots show EPO doses, outcomes, and spending changed following the move to bundled payments. They are constructed using the coefficients from Tables A21–A22 for patients with low, average, and high responsiveness to EPO (i.e., the first, third, and fifth EPO-responsiveness quintiles, respectively).

Figures A8 and A9 are constructed by first plotting the predicted pre-bundle mean monthly EPO dose and relevant outcome for patients in the first, third, and fifth quintile of EPO responsiveness (labeled "Pre-PPS"). From this point, coefficients from the relevant column of Tables A20–A22 are used to predict the EPO and outcome values for these same groups 12 months into the post-bundle period (labeled "Post-PPS"). The plots in Figure 7 in Section 5 are constructed in the same way using estimates presented in Table A20. As EPO doses fell following the bundle, the figures should be read from right to left.

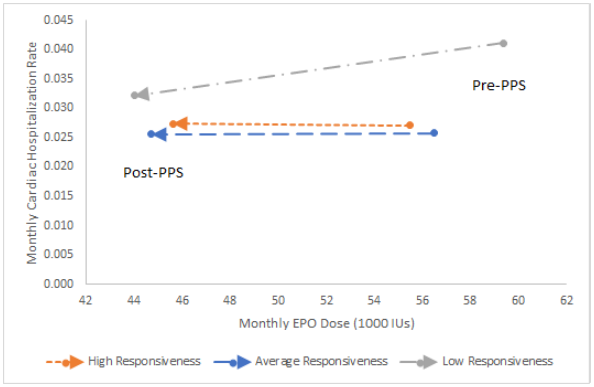
Figure A8
Responsiveness Quintile Changes Across the Bundle: Patient Outcomes



(a) Hemoglobin



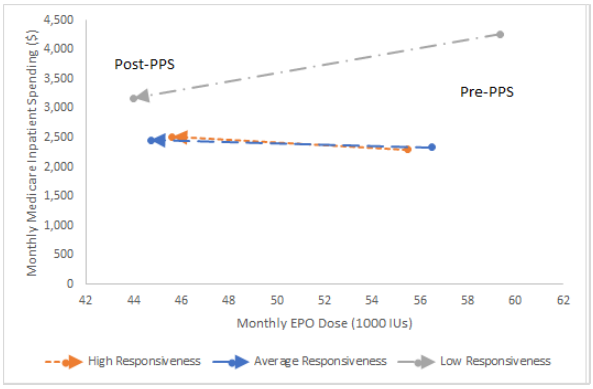
(b) Hospitalization Rate



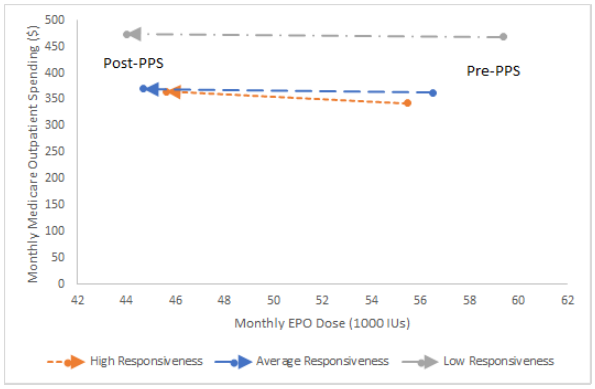
(c) Cardiac Hospitalization Rate

Notes: "High Responsiveness", "Average Responsiveness", and "Low Responsiveness" refer to patients with average estimated marginal effects of EPO on transfusions in the fifth, third, and first quintiles of absolute value, respectively. High-responsiveness patients have an average estimated marginal effect at least 0.78 standard deviations above the mean, while that of low-responsiveness patients is at least 0.73 standard deviations below the mean. Marginal effects are recovered from IV estimates of Equation 6 using a series of dummy variables for each responsiveness quintile, with these estimates presented in Table A21. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter.

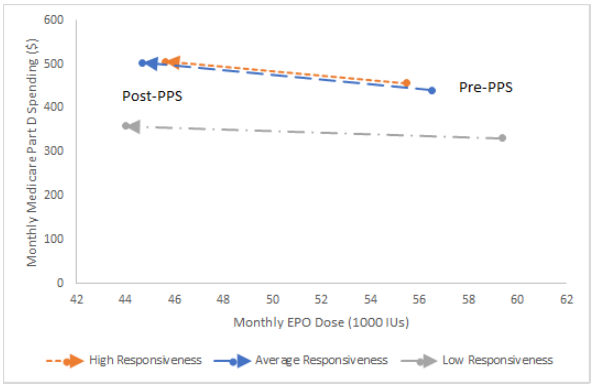
Figure A9
Responsiveness Quintile Changes Across the Bundle: Spending



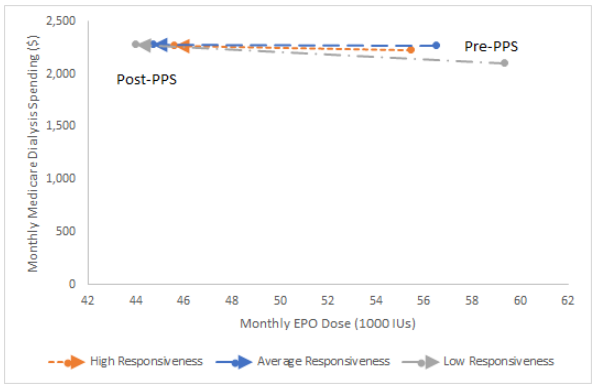
(a) Inpatient Spending



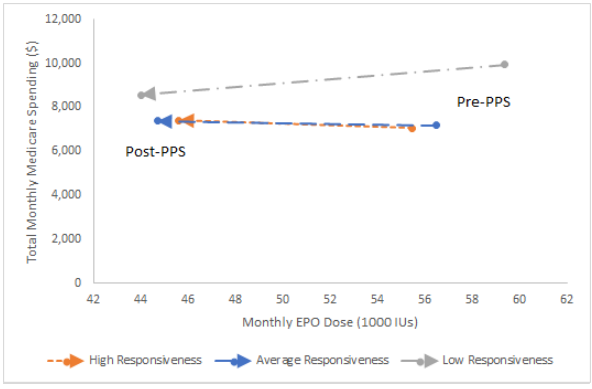
(b) Outpatient Spending



(c) Part D Spending



(d) Dialysis Spending



(e) Total Spending

Notes: "High Responsiveness", "Average Responsiveness", and "Low Responsiveness" refer to patients with average estimated marginal effects of EPO on transfusions in the fifth, third, and first quintiles of absolute value, respectively. High-responsiveness patients have an average estimated marginal effect at least 0.78 standard deviations above the mean, while that of low-responsiveness patients is at least 0.73 standard deviations below the mean. Marginal effects are recovered from IV estimates of Equation 6 using a series of dummy variables for each responsiveness quintile, with these estimates presented in Table A22. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs.

Table A18

Difference in Other Outcomes by Responsiveness of Transfusions to EPO

	(1) HGB	(1) HGB	(3) Hosp., Any Cause	(4) Hosp., Any Cause	(5) Hosp., Cardiac Event	(6) Hosp., Cardiac Event
Estimated MFX Z-Score	0.0449***	0.0454***	-0.0264***	-0.0263***	-0.00457***	-0.00457***
	(0.00137)	(0.00137)	(0.000345)	(0.000345)	(0.000120)	(0.000120)
PPS	-0.231***		0.00108^{+}		0.000124	
	(0.00652)		(0.000588)		(0.000249)	
Estimated MFX Z-Score × PPS	-0.0178***	-0.0184***	0.0113***	0.0112***	0.00229***	0.00228***
	(0.00178)	(0.00179)	(0.000353)	(0.000354)	(0.000138)	(0.000138)
Time Trend	-0.0103***		-0.000603***		-0.000163***	
	(0.000328)		(0.0000259)		(0.0000112)	
Facility Controls	1	1	1	1	1	1
Facility FE	1	1	1	1	1	1
Month FE and Trend	1	0	1	0	1	0
Year-Month FE	0	1	0	1	0	1
R-squared	0.0718	0.0752	0.0139	0.0139	0.00417	0.00418
Dep. Var. Mean	11.12	11.12	0.138	0.138	0.0271	0.0271
Observations	8181736	8181736	10077264	10077264	10077264	10077264

Notes: OLS estimates from equation (8). Dependent variable in columns (1)–(2) is monthly hemoglobin. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. Dependent variables in columns (3)–(6) are binary measures. PPS is an indicator variable for January 2011 or later. Time Trend is a continuous measure of months since January 2011. This means the value for January 2011 is zero, while it is positive for subsequent months and negative for prior months. Post-PPS Trend Change is the interaction of PPS and Time Trend. Estimated MFX Z-Score is the standardized patient-level estimated marginal effect predicted using the IV estimates of 6. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

Table A19

Difference in Medicare Spending by Responsiveness of Transfusions to EPO

	Inpatient		Outpatient		Dialysis		Part D		Total	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
EPO-Responsiveness Z-Score	-638.3***	-634.3***	-40.57***	-40.50***	37.72***	36.41***	40.33***	39.74***	-940.1***	-933.9***
	(9.074)	(9.055)	(0.975)	(0.973)	(1.533)	(1.530)	(1.205)	(1.202)	(12.42)	(12.39)
PPS	25.62		-4.350*		5.326		9.254***		3.096	
	(15.78)		(2.199)		(3.959)		(1.525)		(20.22)	
EPO-Responsiveness Z-Score × PPS	346.0***	337.3***	1.457	1.242	-35.43***	-32.65***	12.62***	13.87***	438.4***	424.8***
	(9.417)	(9.438)	(1.463)	(1.473)	(1.653)	(1.650)	(1.272)	(1.274)	(12.37)	(12.41)
Time Trend	-11.85***		1.277***		3.887***		3.306***		-9.507***	
	(0.694)		(0.111)		(0.167)		(0.0826)		(0.926)	
Facility Controls	1	1	1	1	1	1	1	1	1	1
Facility FE	1	1	1	1	1	1	1	1	1	1
Month FE and Trend	1	0	1	0	1	0	1	0	1	0
Year-Month FE	0	1	0	1	0	1	0	1	0	1
R-squared	0.00995	0.0100	0.0143	0.0144	0.0557	0.0579	0.0388	0.0390	0.0215	0.0217
Dep. Var. Mean	2557.5	2557.5	393.7	393.7	2286.8	2286.8	465.2	465.2	7555.4	7555.4
Observations	9771287	9771287	9771287	9771287	9771287	9771287	9771287	9771287	9771287	9771287

Notes: OLS estimates from equation (8). Dependent variable in columns (1)–(2) is monthly hemoglobin. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. Dependent variables in columns (3)–(8) are binary measures. PPS is an indicator variable for January 2011 or later. Time Trend is a continuous measure of months since January 2011. This means the value for January 2011 is zero, while it is positive for subsequent months and negative for prior months. Post-PPS Trend Change is the interaction of PPS and Time Trend. Estimated MFX Z-Score is the standardized patient-level estimated marginal effect predicted using the IV estimates of 6. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

Table A20
DIFFERENCE IN EPO BY THE RESPONSIVENESS OF TRANSFUSION RATES TO EPO, QUINTILES

	(1) EPO	(2) EPO	(3) Transfusion	(4) Transfusion	(5) Mortality	(6) Mortality
Second Quintile of EPO-Responsiveness	-2.042***	-1.867***	-0.0256***	-0.0255***	-0.0240***	-0.0240***
	(0.318)	(0.318)	(0.000477)	(0.000477)	(0.000301)	(0.000301)
Third Quintile of EPO-Responsiveness	-2.883***	-2.472***	-0.0289***	-0.0289***	-0.0256***	-0.0256***
	(0.324)	(0.323)	(0.000479)	(0.000478)	(0.000311)	(0.000311)
Fourth Quintile of EPO-Responsiveness	-3.093***	-2.588***	-0.0299***	-0.0298***	-0.0251***	-0.0251***
	(0.319)	(0.318)	(0.000472)	(0.000471)	(0.000307)	(0.000308)
Fifth Quintile of EPO-Responsiveness	-3.905***	-3.380***	-0.0299***	-0.0298***	-0.0246***	-0.0246***
	(0.328)	(0.328)	(0.000483)	(0.000482)	(0.000310)	(0.000311)
PPS	-9.149***		-0.00776***		-0.0130***	
	(0.362)		(0.000513)		(0.000332)	
Second Quintile of EPO-Responsiveness × PPS	1.602***	1.011**	0.0127***	0.0126***	0.0149***	0.0149***
	(0.318)	(0.317)	(0.000529)	(0.000529)	(0.000326)	(0.000328)
Third Quintile of EPO-Responsiveness × PPS	3.588***	2.687***	0.0158***	0.0157***	0.0164***	0.0165***
	(0.319)	(0.316)	(0.000543)	(0.000544)	(0.000330)	(0.000332)
Fourth Quintile of EPO-Responsiveness × PPS	4.177***	3.151***	0.0162***	0.0160***	0.0162***	0.0162***
	(0.317)	(0.315)	(0.000532)	(0.000533)	(0.000331)	(0.000334)
Fifth Quintile of EPO-Responsiveness × PPS	5.513***	4.447***	0.0173***	0.0172***	0.0167***	0.0167***
	(0.329)	(0.327)	(0.000542)	(0.000543)	(0.000335)	(0.000338)
Time Trend	-0.518***		-0.0000865***		-0.000112***	
	(0.0145)		(0.0000123)		(0.00000805)	
Facility Controls	1	1	1	1	1	1
Facility FE	1	1	1	1	1	1
Month FE and Trend	1	0	1	0	1	0
Year-Month FE	0	1	0	1	0	1
R-squared	0.123	0.125	0.00945	0.00948	0.00533	0.00533
Dep. Var. Mean	48.27	48.27	0.0282	0.0282	0.0157	0.0157
Observations	10077264	10077264	10077264	10077264	10077264	10077264

Notes: OLS estimates from equation (8). Dependent variable in columns (1)–(2) is monthly EPO dose. EPO doses are winsorized at the 99th percentile and measured in 1000 IUs. Dependent variables in columns (3)–(6) are binary outcome measures. PPS is an indicator variable for January 2011 or later. Time Trend is a continuous measure of months since January 2011. This means the value for January 2011 is zero, while it is positive for subsequent months and negative for prior months. Post-PPS Trend Change is the interaction of PPS and Time Trend. Estimated MFX Z-Score is the standardized patient-level estimated marginal effect predicted using the IV estimates of 6. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

Table A21

Difference in Other Outcomes by the Responsiveness of Transfusion Rates to EPO, Quintiles

	(1) HGB	(1) HGB	(3) Hosp., Any Cause	(4) Hosp., Any Cause	(5) Hosp., Cardiac Event	(6) Hosp., Cardiac Event
Second Quintile of EPO-Responsiveness	0.145***	0.146***	-0.0708***	-0.0707***	-0.0133***	-0.0133***
	(0.00400)	(0.00400)	(0.00101)	(0.00101)	(0.000385)	(0.000385)
Third Quintile of EPO-Responsiveness	0.151***	0.152***	-0.0822***	-0.0821***	-0.0153***	-0.0153***
	(0.00404)	(0.00404)	(0.00101)	(0.00101)	(0.000370)	(0.000370)
Fourth Quintile of EPO-Responsiveness	0.143***	0.145***	-0.0829***	-0.0828***	-0.0151***	-0.0151***
	(0.00404)	(0.00403)	(0.00101)	(0.00101)	(0.000381)	(0.000381)
Fifth Quintile of EPO-Responsiveness	0.143***	0.145***	-0.0812***	-0.0810***	-0.0140***	-0.0140***
	(0.00423)	(0.00423)	(0.00105)	(0.00105)	(0.000381)	(0.000381)
PPS	-0.171***		-0.0339***		-0.00692***	
	(0.00749)		(0.000984)		(0.000400)	
Second Quintile of EPO-Responsiveness × PPS	-0.0660***	-0.0664***	0.0344***	0.0342***	0.00739***	0.00737***
	(0.00478)	(0.00478)	(0.00109)	(0.00109)	(0.000432)	(0.000433)
Third Quintile of EPO-Responsiveness × PPS	-0.0758***	-0.0778***	0.0448***	0.0445***	0.00884***	0.00881***
	(0.00496)	(0.00497)	(0.00110)	(0.00110)	(0.000425)	(0.000426)
Fourth Quintile of EPO-Responsiveness × PPS	-0.0667***	-0.0693***	0.0454***	0.0451***	0.00922***	0.00919***
	(0.00498)	(0.00498)	(0.00108)	(0.00108)	(0.000439)	(0.000441)
Fifth Quintile of EPO-Responsiveness × PPS	-0.0851***	-0.0879***	0.0473***	0.0470***	0.00922***	0.00918***
	(0.00553)	(0.00554)	(0.00110)	(0.00110)	(0.000435)	(0.000437)
Time Trend	-0.0102***		-0.000632***		-0.000169***	
	(0.000328)		(0.0000259)		(0.0000113)	
Facility Controls	1	1	1	1	1	1
Facility FE	1	1	1	1	1	1
Month FE and Trend	1	0	1	0	1	0
Year-Month FE	0	1	0	1	0	1
R-squared	0.0721	0.0756	0.0147	0.0147	0.00433	0.00434
Dep. Var. Mean	11.12	11.12	0.138	0.138	0.0271	0.0271
Observations	8181736	8181736	10077264	10077264	10077264	10077264

Notes: OLS estimates from equation (8). Dependent variable in columns (1)–(2) is monthly hemoglobin. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. Dependent variables in columns (3)–(6) are binary measures. PPS is an indicator variable for January 2011 or later. Time Trend is a continuous measure of months since January 2011. This means the value for January 2011 is zero, while it is positive for subsequent months and negative for prior months. Post-PPS Trend Change is the interaction of PPS and Time Trend. Estimated MFX Z-Score is the standardized patient-level estimated marginal effect predicted using the IV estimates of 6. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

Table A22
Difference in Medicare Spending by the Responsiveness of Transfusion Rates to EPO, Quintiles

	Inpatient		Outpatient		Dialysis		Part D		Total	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Second Quintile of EPO-Responsiveness	-1693.9***	-1689.5***	-76.81***	-76.74***	146.3***	144.5***	77.74***	77.08***	-2392.8***	-2386.1***
	(26.77)	(26.75)	(3.083)	(3.082)	(4.252)	(4.252)	(3.435)	(3.434)	(36.36)	(36.35)
Third Quintile of EPO-Responsiveness	-1927.3***	-1917.6***	-105.7***	-105.6***	171.8***	168.2***	108.5***	107.0***	-2751.9***	-2737.1***
	(26.71)	(26.68)	(3.039)	(3.038)	(4.281)	(4.282)	(3.494)	(3.489)	(36.59)	(36.55)
Fourth Quintile of EPO-Responsiveness	-1955.2***	-1943.5***	-124.4***	-124.1***	172.0***	167.9***	117.4***	115.6***	-2818.3***	-2800.3***
	(26.41)	(26.37)	(3.050)	(3.047)	(4.271)	(4.274)	(3.543)	(3.539)	(36.21)	(36.16)
Fifth Quintile of EPO-Responsiveness	-1968.1***	-1956.0***	-125.8***	-125.6***	128.4***	124.2***	125.1***	123.2***	-2874.9***	-2856.2***
	(27.75)	(27.72)	(3.077)	(3.075)	(4.344)	(4.343)	(3.529)	(3.525)	(38.36)	(38.32)
PPS	-937.7***		-9.663**		131.2***		-13.61***		-1245.6***	
	(26.77)		(3.480)		(5.047)		(2.934)		(34.73)	
Second Quintile of EPO-Responsiveness × PPS	997.9***	983.5***	-8.062*	-8.459*	-145.1***	-140.3***	27.38***	29.49***	1262.5***	1239.8***
	(28.55)	(28.55)	(3.823)	(3.824)	(4.599)	(4.600)	(3.676)	(3.684)	(37.64)	(37.65)
Third Quintile of EPO-Responsiveness × PPS	1211.6***	1190.3***	2.778	2.310	-172.0***	-164.7***	34.99***	38.23***	1573.5***	1540.5***
	(29.20)	(29.22)	(3.736)	(3.741)	(4.538)	(4.543)	(3.750)	(3.754)	(38.89)	(38.90)
Fourth Quintile of EPO-Responsiveness × PPS	1226.7***	1202.8***	13.57***	13.06***	-164.8***	-156.8***	31.11***	34.77***	1596.1***	1558.9***
	(28.66)	(28.68)	(3.780)	(3.784)	(4.545)	(4.549)	(3.902)	(3.910)	(37.78)	(37.81)
Fifth Quintile of EPO-Responsiveness × PPS	1307.2***	1282.3***	17.52***	16.99***	-136.1***	-127.8***	21.68***	25.50***	1710.9***	1672.3***
	(29.21)	(29.25)	(3.903)	(3.914)	(4.743)	(4.748)	(3.783)	(3.786)	(38.64)	(38.70)
Time Trend	-12.43***		1.171***		3.942***		3.423***		-10.32***	
	(0.694)		(0.110)		(0.167)		(0.0825)		(0.926)	
Facility Controls	1	1	1	1	1	1	1	1	1	1
Facility FE	1	1	1	1	1	1	1	1	1	1
Month FE and Trend	1	0	1	0	1	0	1	0	1	0
Year-Month FE	0	1	0	1	0	1	0	1	0	1
R-squared	0.0105	0.0105	0.0145	0.0146	0.0567	0.0589	0.0395	0.0398	0.0221	0.0223
Dep. Var. Mean	2557.5	2557.5	393.7	393.7	2286.8	2286.8	465.2	465.2	7555.4	7555.4
Observations	9771287	9771287	9771287	9771287	9771287	9771287	9771287	9771287	9771287	9771287

Notes: OLS estimates from equation (8). Dependent variables are components of Medicare spending, denominated in dollars. PPS is an indicator variable for January 2011 or later. Time Trend is a continuous measure of months since January 2011. This means the value for January 2011 is zero, while it is positive for subsequent months and negative for prior months. Post-PPS Trend Change is the interaction of PPS and Time Trend. Estimated MFX Z-Score is the standardized patient-level estimated marginal effect predicted using the IV estimates of 6. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

Table A23

Difference in Other Outcomes by Responsiveness of Transfusions to EPO and Chain Status

	(1) HGB	(1) HGB	(3) Hosp., Any Cause	(4) Hosp., Any Cause	(5) Hosp., Cardiac Event	(6) Hosp., Cardiac Event
Chain Ownership	0.0191	0.00193	0.00257	0.00322	0.00166*	0.00175*
	(0.0244)	(0.0214)	(0.00214)	(0.00206)	(0.000761)	(0.000706)
EPO-Responsiveness Z-Score	0.0445***	0.0442***	-0.0260***	-0.0260***	-0.00409***	-0.00416***
	(0.00349)	(0.00364)	(0.000743)	(0.000728)	(0.000241)	(0.000236)
EPO-Responsiveness Z-Score × Chain	0.000445	0.00144	-0.000526	-0.000378	-0.000614*	-0.000528+
	(0.00378)	(0.00401)	(0.000837)	(0.000817)	(0.000278)	(0.000271)
PPS	-0.207***		0.000750		0.000385	
	(0.0212)		(0.00115)		(0.000508)	
PPS × Chain	-0.0306		0.000379		-0.000342	
	(0.0221)		(0.00127)		(0.000557)	
EPO-Responsiveness Z-Score × PPS	-0.0106*	-0.0109*	0.0115***	0.0113***	0.00185***	0.00185***
	(0.00501)	(0.00493)	(0.000746)	(0.000743)	(0.000294)	(0.000293)
EPO-Responsiveness Z-Score × PPS × Chain	-0.00858	-0.00903+	-0.000160	-0.000190	0.000573+	0.000553+
	(0.00534)	(0.00526)	(0.000848)	(0.000844)	(0.000334)	(0.000333)
Time Trend	-0.0108***		-0.000533***		-0.000139***	
	(0.000835)		(0.0000478)		(0.0000205)	
Time Trend × Chain	0.000633		-0.0000846+		-0.0000294	
	(0.000811)		(0.0000513)		(0.0000217)	
Facility Controls	1	1	1	1	1	1
Facility FE	1	1	1	1	1	1
Month FE and Trend	1	0	1	0	1	0
Year-Month FE	0	1	0	1	0	1
R-squared	0.0718	0.0752	0.0139	0.0139	0.00417	0.00418
Dep. Var. Mean	11.12	11.12	0.138	0.138	0.0271	0.0271
Observations	8181736	8181736	10077264	10077264	10077264	10077264

Notes: OLS estimates from equation (8). Dependent variable in columns (1)–(2) is hemoglobin. Hemoglobin is winsorized from below to 5 and from above to 20 and is measured in grams per deciliter. Dependent variables in columns (3)–(6) are binary outcome measures. PPS is an indicator variable for January 2011 or later. Time Trend is a continuous measure of months since January 2011. This means the value for January 2011 is zero, while it is positive for subsequent months and negative for prior months. Post-PPS Trend Change is the interaction of PPS and Time Trend. Estimated MFX Z-Score is the standardized patient-level estimated marginal effect predicted using the IV estimates of 6. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

Table A24

Difference in Medicare Spending by Responsiveness of Transfusions to EPO and Chain Status

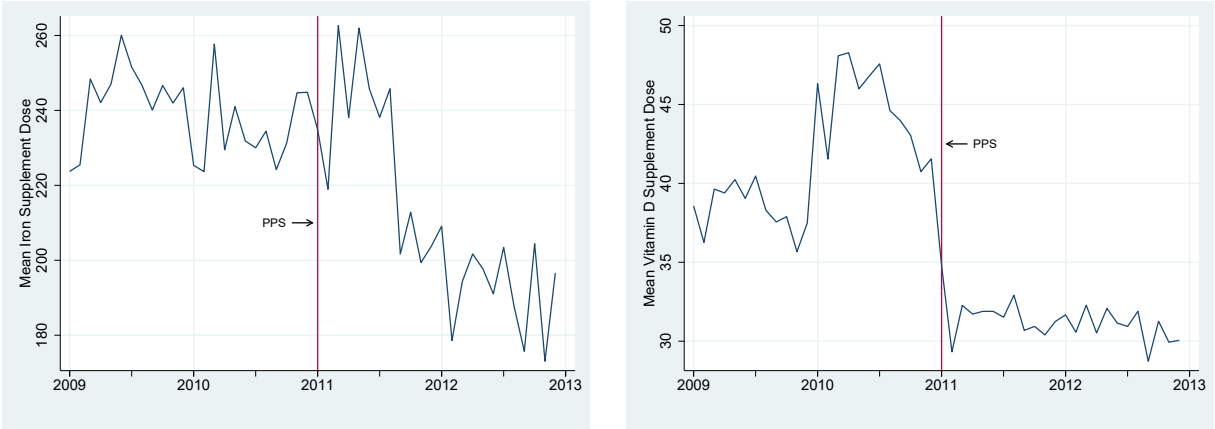
	Inpatient		Outpatient		Dialysis		Part D		Total	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Chain Ownership	63.29	43.97	3.742	4.061	24.55	-13.75	36.99***	27.30**	191.9**	97.74
	(46.07)	(41.98)	(8.912)	(8.490)	(22.09)	(21.40)	(8.610)	(8.308)	(70.92)	(65.37)
EPO-Responsiveness Z-Score	-673.5***	-668.5***	-40.63***	-40.75***	44.27***	38.76***	37.97***	38.56***	-998.7***	-997.1***
	(22.12)	(21.64)	(2.121)	(2.101)	(3.239)	(3.381)	(2.663)	(2.634)	(29.70)	(28.92)
EPO-Responsiveness Z-Score × Chain	45.10+	43.90+	0.0838	0.322	-8.172*	-2.970	2.980	1.533	75.23*	81.07*
	(24.18)	(23.56)	(2.375)	(2.349)	(3.668)	(3.809)	(2.975)	(2.933)	(32.59)	(31.64)
PPS	55.25		-3.191		94.67***		18.51***		191.8***	
	(35.05)		(4.667)		(8.624)		(3.573)		(45.65)	
PPS × Chain	-35.69		-1.385		-111.2***		-10.65**		-233.6***	
	(37.79)		(5.029)		(9.484)		(3.816)		(48.95)	
EPO-Responsiveness Z-Score × PPS	334.0***	325.3***	-0.0388	-0.180	-32.73***	-28.08***	15.82***	16.79***	422.0***	411.5***
	(22.07)	(21.99)	(2.898)	(2.892)	(3.375)	(3.524)	(2.811)	(2.826)	(28.79)	(28.58)
EPO-Responsiveness Z-Score × PPS × Chain	12.98	12.85	1.838	1.741	-3.304	-5.549	-3.992	-3.697	16.86	12.98
	(24.38)	(24.25)	(3.344)	(3.338)	(3.882)	(4.004)	(3.175)	(3.190)	(31.90)	(31.63)
Time Trend	-13.08***		1.330***		2.892***		2.436***		-13.23***	
	(1.384)		(0.213)		(0.303)		(0.164)		(1.856)	
Time Trend × Chain	1.466		-0.0708		1.337***		1.044***		4.642*	
	(1.438)		(0.216)		(0.309)		(0.173)		(1.920)	
Facility Controls	1	1	1	1	1	1	1	1	1	1
Facility FE	1	1	1	1	1	1	1	1	1	1
Month FE and Trend	1	0	1	0	1	0	1	0	1	0
Year-Month FE	0	1	0	1	0	1	0	1	0	1
R-squared	0.00996	0.0100	0.0143	0.0144	0.0559	0.0579	0.0388	0.0390	0.0215	0.0217
Dep. Var. Mean	2557.5	2557.5	393.7	393.7	2286.8	2286.8	465.2	465.2	7555.4	7555.4
Observations	9771287	9771287	9771287	9771287	9771287	9771287	9771287	9771287	9771287	9771287

Notes: OLS estimates from equation (8). Dependent variables are components of Medicare spending, denominated in dollars. PPS is an indicator variable for January 2011 or later. Time Trend is a continuous measure of months since January 2011. This means the value for January 2011 is zero, while it is positive for subsequent months and negative for prior months. Post-PPS Trend Change is the interaction of PPS and Time Trend. Estimated MFX Z-Score is the standardized patient-level estimated marginal effect predicted using the IV estimates of 6. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.

H. Other Drugs

In addition to EPO, IV iron and vitamin D are common classes of injectable drugs administered to treat anemia in dialysis facilities. Like EPO, these were separately billable prior to 2011 but bundled together with dialysis in the PPS reform. Unlike EPO, these classes of drugs were not the subject of any changes in clinical guidelines, such as the black box warning for EPO issued by the FDA in mid-2011. Figure A10 shows that, similar to EPO, there was a decline in the use of these two classes of drugs, lending credence to our interpretation that financial incentives effectively reduced the quantity of anemia drugs given to dialysis patients.

Figure A10
Use of Other Injectable Drugs



(a) Mean Monthly IV Iron Dose

(b) Mean Monthly Vitamin D Dose

Notes: An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. The vertical line indicates the start of PPS in January 2011.

Table A25
Effect of Bundle on Injectable Drugs

	(1) IV Iron	(2) IV Iron	(3) Vitamin D	(4) Vitamin D
PPS	-16.50***	16.71***	-11.15***	-16.25***
	(2.193)	(2.014)	(0.499)	(0.946)
Time Trend		-0.473***		0.461***
		(0.109)		(0.0507)
Post-PPS Trend Change		-2.597***		-0.420***
		(0.128)		(0.0493)
Pat/Fac Controls	1	1	1	1
Facility FE	1	1	1	1
Dep. Var. Mean	224.4	224.4	36.28	36.28
R-squared	0.0660	0.0685	0.0747	0.0754
Observations	8869420	8869420	10077264	10077264

Notes: OLS estimates from equation (2). Dependent variable in columns (1) and (2) is total intravenously injectable iron supplement usage. Dependent variable in columns (3) and (4) is total injectable vitamin D supplement usage. PPS is an indicator variable for January 2011 or later. Time Trend is a continuous measure of months since January 2011. This means the value for January 2011 is zero, while it is positive for subsequent months and negative for prior months. Post-PPS Trend Change is the interaction of PPS and Time Trend. An observation is a patient-month. Sample consists of observations from January 2009 to December 2012 for hemodialysis patients between the ages of 18 and 100 with Medicare as their primary payer for whom we observe all patient and facility controls used in the analyses in Section 3.1 and later. Patient controls include dummy variables for comorbidities from medical evidence forms, patient demographics, age, and dialysis tenure. Facility controls include facility elevation, whether the facility is freestanding or hospital-based, and chain ownership, as well as facility fixed effects. Further controls include calendar month fixed effects. Standard errors clustered by facility are in parentheses. $^{+}$, *, ** and *** indicate significance at the 10%, 5%, 1% and 0.1% level, respectively.