Supplemental Appendix to:

"Market Consolidation and Mortality in Patients Initiating Hemodialysis"

Detailed Methods:

Determining Facility Ownership and Acquisitions

We used two data sources to identify dialysis facility owners: Annual dialysis facility surveys included in the United States Renal Data System (USRDS) database, and data from Dialysis Facility Compare (DFC). When obtaining data from DFC, we used ownership from the report closest in time to January 1st of the calendar year of interest. When we examined changes in ownership following the two large acquisitions, we noticed that the Annual Facility Surveys appeared more accurate. Notably, a small number of facilities that were acquired continued to report the previous owner in DFC through as late as 2011. We suspect that this is because DFC relies on facilities reporting ownership changes to their regional end-stage renal disease (ESRD) Network, while the facility survey is required to be completed by each facility annually.

Because the facility survey and DFC both contained information about large dialysis facility chains, we used the more up-to-date data contained in the Facility Reports to assign ownership to facilities when a facility was noted to be owned by a large chain in the Facility Report. However, the Facility Report did not contain information about many smaller regional chains. In instances where the Facility Report did not report a facility as being owned by a large chain, but where DFC assigned a facility to a regional chain, we used the DFC data to assign ownership. Only in instances where both the Facility Report and DFC listed a facility as being independent did we consider it as such.

During the "transition period" for each acquisition, more than 80% of facilities that were acquired were reported as having changed ownership. When following facilities for additional years, we observed that virtually all of the remaining facilities that were owned by the acquired organizations ended up being reported to change ownership. We chose the specific transition period lengths that we did in order to include as many facilities that changed ownership as possible, while minimizing the gap in time between the pre-and post-acquisition periods. While adding an additional year to the transition period would capture even more acquired facilities, it would increase the likelihood of bias due to unobserved changes over time in health between treatment and control groups.

Assigning Patients to an Acquisition Group

Many patients initiating dialysis could be assigned to either acquisition group (i.e. the group representing Fresenius' or the DaVita's acquisitions). In order to avoid considering the same patient more than once in our cohort, we assigned each patient to only one acquisition group. Assignment to an acquisition group had potential implications regarding whether or not we identified a patient as being affected by consolidation and regarding the specific follow-up duration for each patient, since each acquisition group had different pre-acquisition and post-acquisition follow-up periods. We assigned patients to an acquisition group prior to determining whether or not they were actually "affected" by consolidation. We used the following steps to assign patients to an acquisition group based on the acquisition that had the largest effect on competition in a given Hospital Service Area (HSA):

1) If the HSA where a patient lived when starting dialysis had a facility that was acquired by only one major chain (i.e. Fresenius or DaVita) in the acquisition period, but no facilities acquired by the other chain, patients in that HSA would be assigned to the acquisition that occurred in their HSA.

2) If the HSA where a patient lived had facilities acquired by both major chains, patients living in that HSA would be assigned to the acquisition group which corresponded to the largest increase in HHI before versus after the acquisition.
3) If patients lived in HSAs where no facilities were acquired by either major chain, then patients were assigned to a "control" acquisition comparison at random.

Measuring Competition

The equation used to calculate Herfindahl-Hirschman Index (HHI) is as follows:

$$HHI_{hospital\ service\ area} = \sum_{i=1}^{n} s_i^2$$

Where S_i represents the proportion of patients living in an HSA receiving dialysis at the i^{th} firm in the HSA.

We calculate a measure of "observed HHI" for each hospital service area (HSA) from the following three steps:

1. Calculate a "first-stage" competition measure for each HSA (using the equation above), based on sum of squared market shares of firms where patients living in each HSA choose to dialyze. In this stage all patients residing in a given HSA define the "market" for each firm-HSA pair. Firms do not have to be located in the same HSA where patients reside, and a given dialysis facility can be included in the calculation of HHI for multiple HSAs if patients from multiple HSAs dialyze at that facility. For the purposes of this step, facilities owned by the same dialysis chain were considered to be one firm. The market share for a firm in an HSA is equal to the proportion of patients in that HSA who choose to dialyze at that firm. For example, in an HSA where half of the patients receiving dialysis went to one of four facilities owned by one firm and the other half of patients went to one of two facilities owned by a second firm, the market share would be considered to be split evenly across the two firms, with an HHI for that HSA of $0.5^2 + 0.5^2 = 0.5$.

2. Calculate a dialysis-facility-level measure of competition, using a weighted average of the "first-stage" HSA-level HHIs for patients who actually dialyze at each facility. This measure is calculated for each separate facility, regardless of which firm owns a facility. It assumes that facilities compete for patients within HSAs and can discriminate against patients living in different HSAs when competing against rival firms.

3. Calculate a "second-stage" HSA-level measure of competition from a weighted average of the facility-level-HHIs at facilities where patients residing in each HSA receive dialysis.

In summary, this index represents a weighted average of competition indices for facilities that treat patients in a given HSA, where facility competition indexes are, in turn, weighted by choices available to patients they treat.

Difference-in-Differences Model

The difference-in-differences model estimated whether the change in hazard of death among patient starting dialysis before versus after acquisitions depended upon whether or not they were affected by consolidation. Below is the equation used in our primary analyses:

$$Hazard\ of\ death\ (t) = \lambda_0(t) * e^{[\alpha(Affected) + \beta(PostAcquisition*Affected)) + \gamma 1(Yr2001) + \gamma 2\ (Yr2002) \ldots \gamma 9\ (Yr2009) + \delta(X)]}$$

- *"Affected"* is a binary variable that denotes whether a patients lived in a hospital service area that was affected by consolidation. The criteria used to define *"Affected"* varied in our two primary analyses.
- *"PostAcquisition"* is a binary variable denoting whether a patient initiated dialysis in the post-acquisition period. Note that this variable only appears in the model as an interaction term with *"Affected."* This is because dummy variables for each calendar year capture, with more granularity, differences in mortality in the pre – and post – acquisition periods that are independent of whether patients are affected by acquisitions. The actual calendar years that define the *PostAcquisition* period differ depending on the acquisition to which a patient is assigned.
- *"Yr2001"* through *"Yr2009"* are dummy variables representing the calendar year when patients initiate dialysis.
- *"X"* is a vector of all model covariates. In addition to covariates included in **Table 1** of the main manuscript text, it includes five additional dummy variables denoting whether or not patients initiated dialysis at each of the five largest dialysis chains.

Within this model framework, β represents an estimate of the effect of consolidation on the hazard of death.

Examination of Proportional Hazards Assumption

We examined our primary analytic model for violation of the proportional hazards assumption by testing for a nonzero slope in a generalized linear regression of scaled Schoenfeld residuals on time. This was done in the following steps:

1) We tested the null hypothesis that the slope for the scaled Schoenfeld residual on time for each model covariate was zero, and the global hypothesis that all slopes were zero. This was done by extracting 3 imputations (one using our "complete case" cohort, and two of the five multiply imputed datasets).
2) In all three extracted imputations, we rejected the null hypothesis of a non-zero joint slope. We observed that the same covariates consistently displayed non-proportional hazards over time.
3) We selected the following list of individual covariates where the p-value testing the hypothesis that the slope was zero was less than 0.05: micropolitan location, immobile, male sex, employed, hospital facility, facility size, diabetes, cancer, smoking history, each albumin category, age between 65 and 75.
4) We then separated follow-up time into 90 day intervals, and created time-varying interaction terms between each selected covariate and each interval of follow-up time.
5) For each extracted imputation, we ran a second model where each selected covariate was replaced by its time-varying equivalent. We tested the Schoenfeld residuals following each of these models. In all three models, we were unable to reject the null hypothesis that each selected covariate*follow-up period term did not vary over time. Additionally, in each model we were unable to reject the global null hypothesis that all variables did not vary over time.
6) Finally, we used the expanded model with time-varying interaction terms to generate a new estimate from the fully imputed data that did not violate the proportional hazards assumption.

Results: The estimated effect of consolidation on the hazard of death was virtually identical in this expanded model using multiple imputation and selected coefficients interacted with follow-up time (HR 1.08; 95% CI (1.00 to 1.16)).

Sensitivity Analyses

We conducted the following analyses to examine the sensitivity of our primary model examining the association between consolidation and mortality in patients living in areas where the HHI increased by ≥0.1 to various assumptions.

1) We examined the sensitivity of our findings to the use of the "90-day rule", where we require that patients survive on dialysis for 90 days. This rule is commonly used when analyzing data from the United States Renal Data System in order to establish a relatively stable dialysis cohort and ensure that patients actually have end-stage renal disease. When examining sensitivity to the 90-day rule, we assigned patients to the HSA where they lived and the facility where they received dialysis at the onset of ESRD. Similar to our primary analyses, we censored patients for death, relocation to a new HSA for more than 60 days, or renal recovery. Rather than requiring that they live for 90 days, we began assessing mortality after the first day of initiating dialysis.

Results: The findings from a sensitivity analysis where we included patients who died in the first 90 days of dialysis were not substantively different from the primary results. Notably, patients living in areas affected by consolidation and where the HHI increased by ≥0.1 had a 6% increase in the hazard of death following consolidation (HR=1.06; 95%CI, 0.98-*1.14).*

2) We assessed whether our findings differed if we excluded patients receiving dialysis at facilities that were acquired. This analysis was motivated by the possibility that facilities that were actually acquired may have had changes in the quality of care delivered that were due to changes in management and not necessarily due to changes in local market competition. This analysis was identical to our primary model, except that we excluded patients within affected HSAs who initiated dialysis at a facility that was acquired, both prior to – or following—acquisitions.

Results: When we excluded patients at facilities that were actually acquired, we found that patients living in areas affected by consolidation and where the HHI increased by ≥0.1 had a 13% increase in the hazard of death following consolidation (HR=1.13; 95%CI, 1.01-1.26) relative to the change in patients initiating dialysis in unaffected areas.

Additional Analyses

We conducted several additional exploratory analyses to learn more about the relation between consolidation and health outcomes:

1) We examined whether the estimated effect of consolidation varied by the two major dialysis chain acquisitions. This was done by first identifying HSAs where an acquisition by one of the LDOs (arbitrarily designated "Provider A") occurred. By definition, all other HSAs where acquisitions occurred involved "Provider B," which served as the reference provider. We then added an interaction term to our primary model which represented patients who: a) initiated dialysis after acquisitions, and; b) lived in an area affected by consolidation where the acquisition involved Provider A. The estimated coefficient associated with this interaction term describes the effect of consolidation on patients receiving dialysis in an area affected by an acquisition from "Provider A" compared to the effect of consolidation on patients receiving dialysis in an area affected by an acquisition from "Provider B". Constructing this model also required including a term representing patients living in areas affected by a "Provider A" acquisition in the pre-acquisition period and terms representing the interaction between patients living in areas affected by a "Provider A" acquisition and each calendar year dummy variable. The model is illustrated below:

$$Hazard\ of\ death\ (t) = \lambda_0(\mathrm{t}) * e^{\left[\alpha*(Aff)+\beta(PostAcq*Aff))+\theta(Aff_{ProvA})+\mu(PostAcq*Aff_{ProvA})*(Aff+\sum_{i=1}^{i=9}[\gamma_i*YR_i]\right]+\sum_{i=1}^{i=9}[\delta_i*YR_i*ProvA]+\propto*X]}$$

Where,

- *"Aff"* denotes patients in areas affected by consolidation involving Provider B (i.e. the reference provider)
- "*PostAcq*Aff"* denotes initiation of dialysis in the period following acquisitions in areas where the acquisition involved provider B.
- *"Aff_{ProvA}"* denotes patients initiating dialysis in areas affected by consolidation involving Provider A in the period prior to acquisition.
- *"PostAcq*Aff_{ProvA}"* denotes initiation of dialysis in the period following acquisitions in areas affected by an acquisition by Provider A
- "YR_i*"* denotes the calendar year of dialysis initiation.
- *"YR_i"*ProvA"* denotes initiation of dialysis in a given calendar year among patients affected by an acquisition involving Provider A
- *"X"* is a vector of covariates

Note that 'μ' represents the differential effect of consolidation among patients initiating dialysis in areas where the acquisition involved Provider A relative to those initiating dialysis in areas where the acquisition involved Provider B.

Results: In this model, consolidation continued to be associated with an increased hazard of death. The estimated increase in hazard of death following consolidation among patients in areas affected by "Provider B" was 17% (HR=1.17; 95%CI, 1.04-1.32). The estimated increase in hazard of death following consolidation among patients in areas affected by "Provider A" was 2% (HR=1.02; 95%CI 0.92-1.13%). However, we were unable to conclude that the effect of consolidation varied among the two different providers (p-value for interaction term assessing for heterogeneity was 0.08) **(Appendix Figure 2)**

2) In order to examine the relation between change in HHI and change in mortality over time, we selected all patients initiating dialysis in HSAs where a facility was acquired and examined whether the change in mortality following consolidation varied according to the magnitude of market consolidation. This was done by separating change in HHI following consolidation into four categories and interacting each of these categories with the variable denoting patients who initiated dialysis in the post-acquisition period

Results: These results are illustrated in **Figure 3** of the manuscript text.

3) We examined the broader association between consolidation and mortality during the study period in an analysis where we considered all acquisitions occurring between 2003 and 2008, regardless of what the acquiring facility was. We chose this specific time period because it enabled us to use the same data set constructed to conduct our primary analysis (2001 through 2009). Because we were not focusing on a specific acquisition, and because we had many more years of possible acquisitions, in this analysis we modified our method of defining both the acquisition periods and the follow-up periods prior to and following acquisitions. We conducted the analysis in the following steps:
    a. We identified acquisitions when there was a documented change in ownership of a facility from one year to the next (e.g. from 2004 to 2005).

b. We defined the acquisition period as the years when ownership changed. For example, if a facility had one owner listed in 2006 and another in 2007, the acquisition period spanned January 1st 2006 through December 31st 2007.
c. We identified patients initiating dialysis in the two years prior to and following each acquisition period. For example, for acquisitions that occurred between 2003 and 2004, we examined changes in mortality among patients initiating dialysis between 2001 and 2002 (pre-acquisition period) and between 2005 and 2006 (post-acquisition period).
d. Similar to our primary analysis, we:
    i. Followed patients from their 90th day of dialysis through their 18th month of dialysis.
    ii. Used the DID model from our primary analysis, comparing mortality between the 4th and 18th months of dialysis among patients in HSAs where acquisitions occurred to those in HSAs where no acquisitions occurred.
    iii. Restricted the analysis to HSAs that were highly concentrated in the two years prior to possible acquisitions (HHI ≥0.25) and that became substantially more consolidation following acquisitions (increase in HHI ≥0.1).
    iv. Excluded facilities that did not have the same owner throughout the pre-acquisition period and throughout the post-acquisition period.
    v. We assigned patients to one acquisition comparison based on the acquisition that had the largest effect on competition in their region or, in the case of "controls", by random selection.

Results: When examining all patients affected by all dialysis facility acquisitions between 2003 and 2008 in highly concentrated regions where the HHI increased by ≥0,1, there were ≈43,000 patients initiating dialysis in HSAs that were affected by acquisitions, and 780,000 patients included in the analysis. We did not observe an effect of consolidation on mortality in this cohort. (HR=1.01; 95%CI, 0.96-1.06) However, a comparison of changes in observable characteristics prior to and following acquisitions among patients living in areas that were and were not affected by consolidation indicates that the populations were different in important health and demographic characteristics. These observable differences in patient populations suggest that, when examining all acquisitions, areas affected by acquisitions may have changed over time in important ways (both observed and possibly unobserved). This may have limited our ability to draw conclusions from this broader comparison. It supports our decision to use the two largest national dialysis chain acquisitions as a method of isolating the effect of consolidation.

Appendix Table 1. Regression Results Examining Patients in Areas that Became Substantially More Consolidated (HHI Increased by ≥0.1)

	HR	LCI	UCI	p-value
Affected	0.98	0.93	1.04	0.59
Affected after acquisition	1.08	1.00	1.17	0.05
Demographic & Socioeconomic				
Age (50 to 65 years is reference)				
18 to 50 years	0.66	0.65	0.68	<0.001
65 to 75 years	1.47	1.44	1.50	<0.001
>75 years	2.12	2.09	2.16	<0.001
Race (white is reference)				
Native American	0.62	0.58	0.67	<0.001
Black	0.76	0.74	0.77	<0.001
Other race	0.60	0.58	0.62	<0.001
Hispanic ethnicity	0.65	0.64	0.67	<0.001
Male	1.01	1.00	1.03	0.04
Medicaid	1.19	1.17	1.21	<0.001
Employed	0.55	0.54	0.57	<0.001
Patient Health Characteristics				
Diabetes	1.05	1.03	1.06	<0.001
Coronary artery disease	1.06	1.04	1.07	<0.001
Cancer	1.43	1.40	1.46	<0.001
heart failure	1.27	1.26	1.29	<0.001
Pulmonary	1.23	1.21	1.25	<0.001
Cerebrovascular disease	1.12	1.10	1.14	<0.001
PVD	1.08	1.06	1.09	<0.001
Smoker	0.99	0.96	1.02	0.57
Drug or alcohol abuse	1.27	1.26	1.29	<.0001
Serum albumin (≥3.5 g/dL is reference)				
<2.0 g/dL	2.06	2.01	2.13	<0.001
2.0 to 3.0 g/dL	1.58	1.56	1.61	<0.001
3.0 to 3.5 g/dL	1.28	1.26	1.31	<0.001
Hemoglobin concentration (≥11 g/dL is reference)				
<8 g/dL	0.98	0.96	1.01	0.26
8 to 9.5 g/dL	1.05	1.03	1.07	<0.001
9.5 to 11 g/dL	1.03	1.01	1.05	0.001
Body mass index (25-30 kg/m^2 is reference)				
<18.5 kg/m^2	1.63	1.59	1.68	<0.001
18.5 to 25 kg/m^2	1.23	1.21	1.25	<0.001
>30 kg/m^2	0.91	0.89	0.92	<0.001
Dialysis Facility and Geographic Characteristics				
For profit facility	1.04	1.01	1.07	0.003
Hospital-based facility	1.09	1.06	1.12	<0.001
Facility size (25 patient change)	2.68	2.67	2.68	<0.001

Note: Regression includes dummy variables for calendar year and 5 largest facility chains. PVD is peripheral vascular disease.

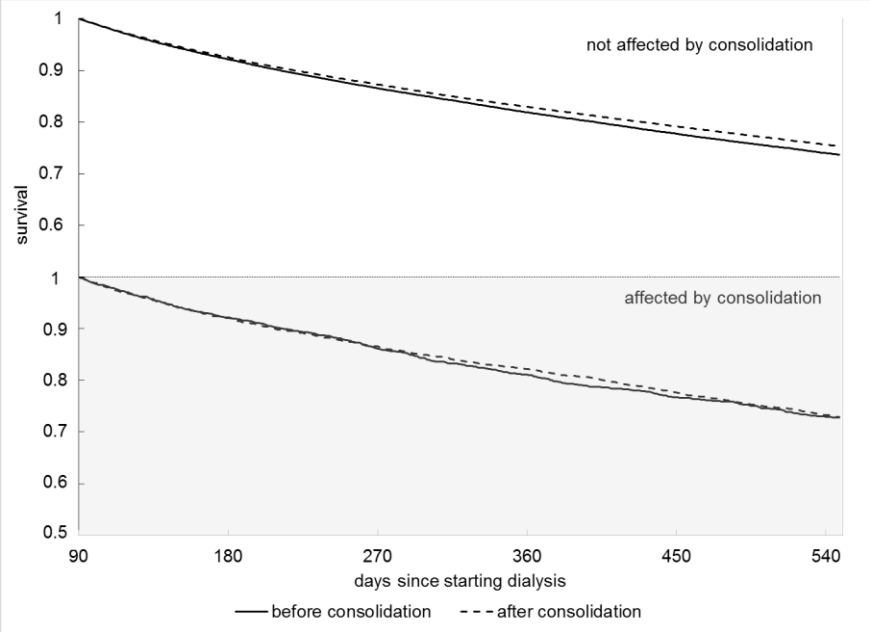
Appendix Table 2. Regression Results for Patients Living in Any Area Affected by an Acquisition.

	HR	LCI	UCI	p-value
Affected	1.05	1.03	1.07	<0.001
Affected after acquisition	1.00	0.97	1.03	0.93
Demographic & Socioeconomic				
Age (50 to 65 years is reference)				
18 to 50 years	0.66	0.65	0.68	<0.001
65 to 75 years	1.47	1.44	1.50	<0.001
>75 years	2.12	2.09	2.16	<0.001
Race (white is reference)				
Native American	0.62	0.58	0.67	<0.001
Black	0.75	0.74	0.76	<0.001
Other race	0.60	0.58	0.62	<0.001
Hispanic ethnicity	0.65	0.64	0.67	<0.001
Male	1.01	1.00	1.03	0.04
Medicaid	1.19	1.17	1.21	<0.001
Employed	0.55	0.54	0.57	<0.001
Patient Health Characteristics				
Diabetes	1.05	1.03	1.06	<0.001
Coronary artery disease	1.06	1.04	1.07	<0.001
Cancer	1.43	1.40	1.46	<0.001
Heart failure	1.27	1.26	1.29	<0.001
Pulmonary	1.23	1.21	1.25	<0.001
Cerebrovascular disease	1.12	1.10	1.14	<0.001
PVD	1.08	1.06	1.10	<0.001
Smoker	0.99	0.97	1.02	0.604
Drug or alcohol abuse	1.27	1.26	1.29	<0.001
Serum albumin (≥3.5 g/dL is reference)				
<2.0 g/dL	2.06	2.00	2.13	<0.001
2.0 to 3.0 g/dL	1.58	1.56	1.61	<0.001
3.0 to 3.5 g/dL	1.28	1.26	1.31	<0.001
Hemoglobin concentration (≥11 g/dL is reference)				
<8 g/dL	0.98	0.96	1.01	0.24
8 to 9.5 g/dL	1.05	1.03	1.07	<0.001
9.5 to 11 g/dL	1.03	1.01	1.05	0.001
Body mass index (25-30 kg/m^2 is reference)				
<18.5 kg/m^2	1.63	1.59	1.68	<0.001
18.5 to 25 kg/m^2	1.23	1.21	1.24	<0.001
>30 kg/m^2	0.91	0.89	0.92	<0.001
Dialysis Facility and Geographic Characteristics				
For profit facility	1.04	1.01	1.06	0.01
Hospital-based facility	1.09	1.06	1.12	<0.001
Facility size (25 patient change)	2.68	2.67	2.69	<0.001

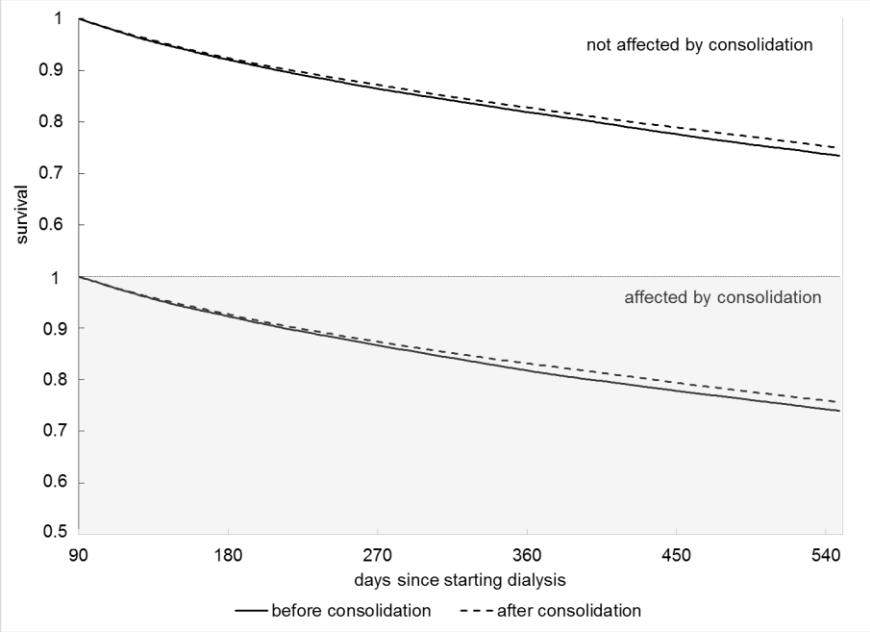
Note: Regression includes dummy variables for calendar year and 5 largest facility chains. PVD is peripheral vascular disease.

Appendix Figure 1. Survival Before and After Consolidation in Affected and Unaffected Patients.

1a. Patients are considered to be affected if markets became substantially more concentrated (HHI increased by ≥0.1).

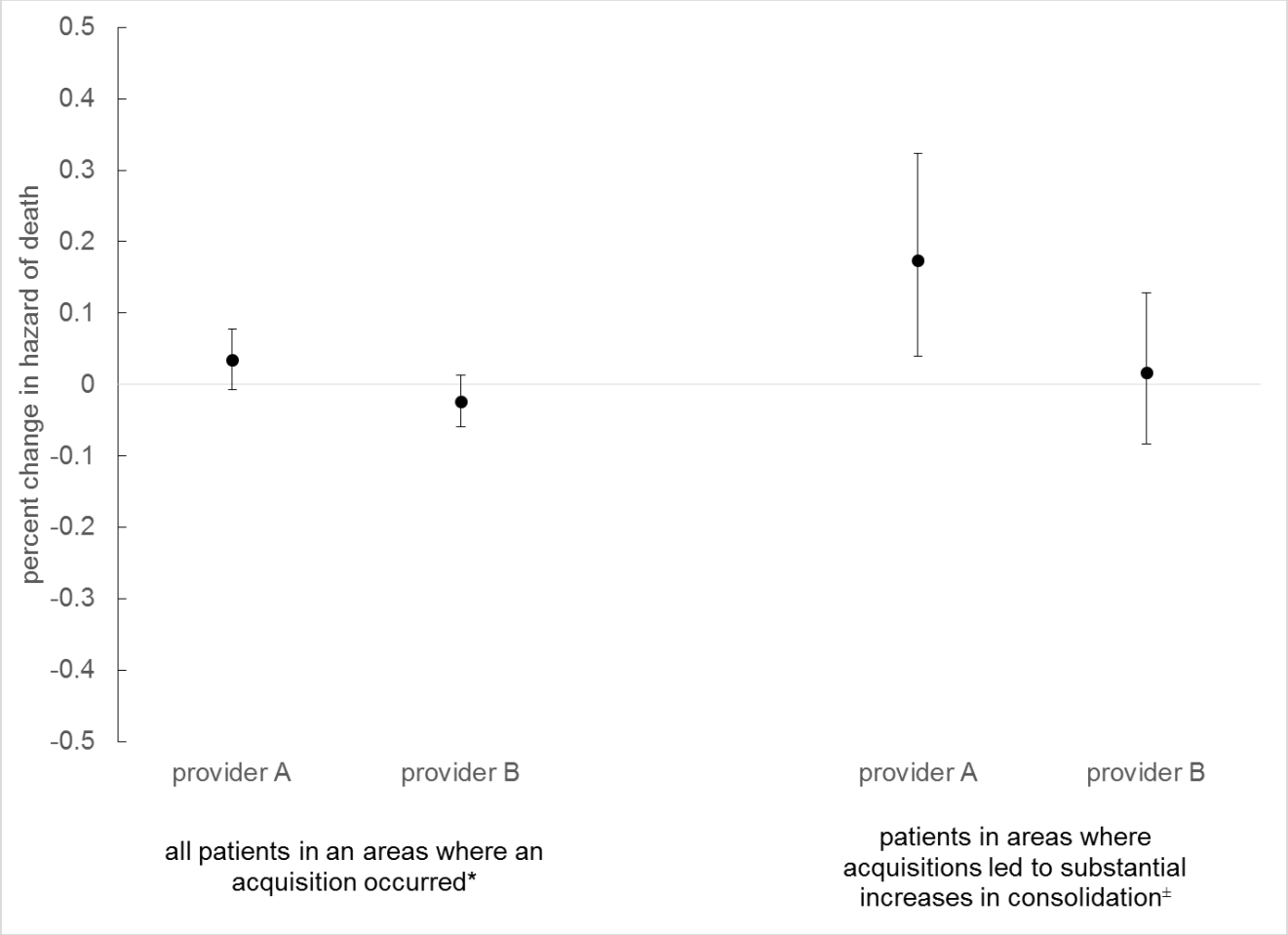


1b. Patients living in any area where an acquisition occurred are considered affected.



Note: HHI is Herfindahl-Hirschman index.

Appendix Figure 2. Estimated Effect of Consolidation Stratified by the Large Dialysis Organization Involved in an Area's Acquisition.



*P-value testing the statistical significance of heterogeneity = 0.039.
±P-value testing the statistical significance of heterogeneity = 0.08.
Note: Estimates are derived from the model described in "**Additional Exploratory Analyses: #1**".

Appendix Figure 3. Change in Herfindahl-Hirschman Index (HHI) over Time by Exposure Groups and Acquiring Facility.

Figure 3a. Acquisition 1

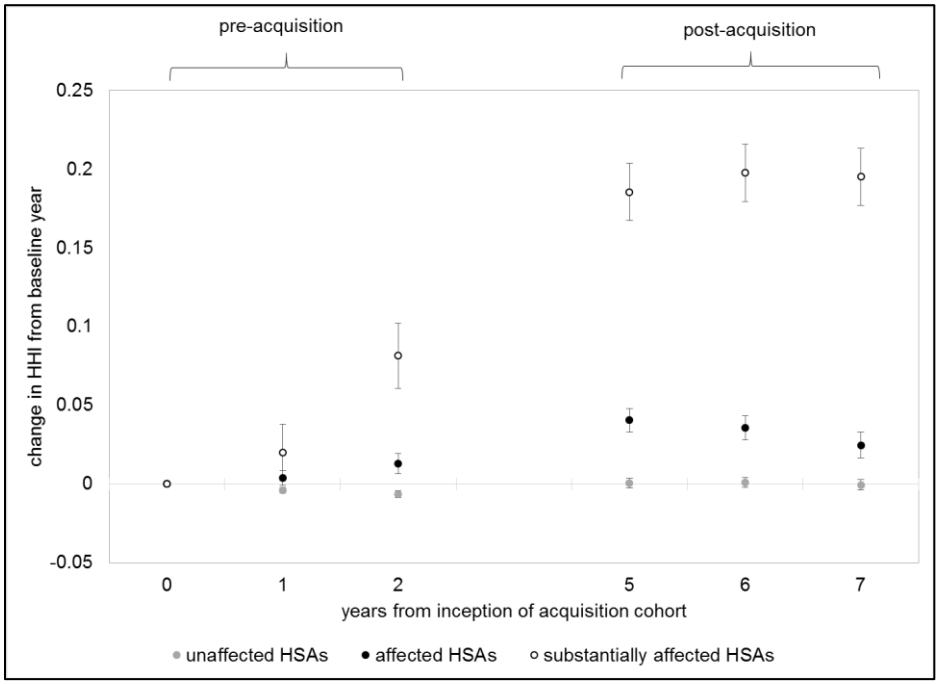
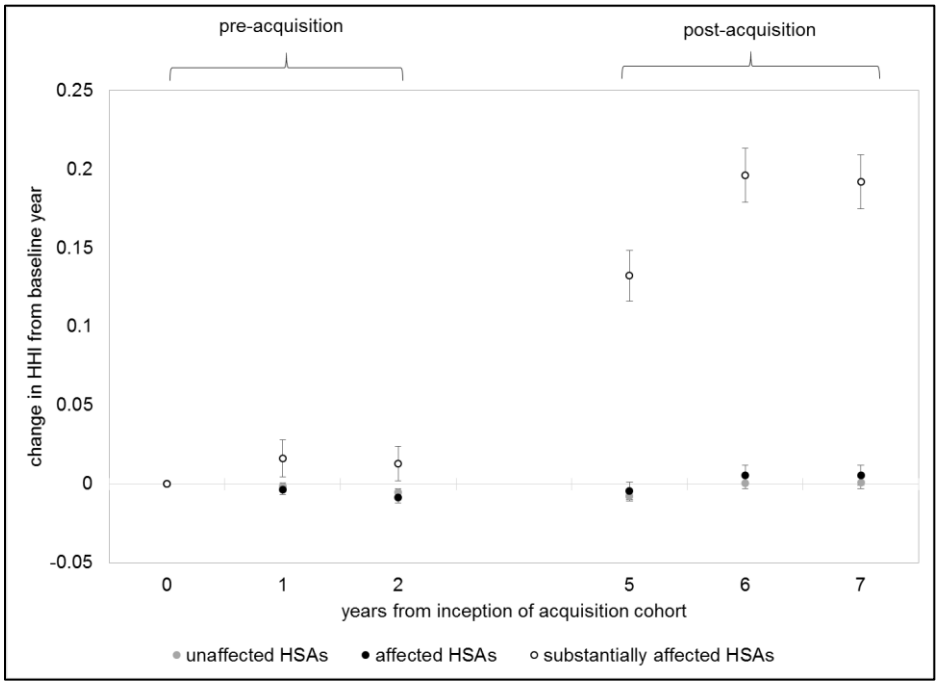


Figure 3b Acquisition 2



Note: Points represent mean changes. Error bars represent standard error of means.