ORIGINAL RESEARCH

Contributions of Geography and Nongeographic Factors to the White-Black Gap in Hospital Quality for Coronary Heart Disease: A Decomposition Analysis

Ioana Popescu, MD, MPH; Peter Huckfeldt, PhD; Joseph D. Pane, MSP; José J. Escarce, MD, PhD

***Background*—**Differences in hospital proximity and nongeographic factors affect disparities in hospital quality for heart disease, but their relative contributions are unknown. The current study quantifies the influences of these factors on the white-black gap in high- and low-quality hospital use for acute myocardial infarction (AMI) and coronary artery bypass grafting (CABG) surgery.

***Methods and Results*—**We used Medicare claims to identify fee-for-service Medicare beneficiaries aged 65 and older hospitalized during 2009–2011 with AMI (n=384 443) and CABG (n=71 411). Hospital quality was measured using publicly available AMI mortality rates. In national and regional analyses, we used conditional multinomial logit models to estimate the white-black gap in high- and low-quality hospital use and decompose the gap into geographic and nongeographic contributions. Overall, more whites used high-quality hospitals for both conditions (34.8% versus 32.4% for AMI; 39.0% versus 29.9% for CABG; $P<0.001$), but after accounting for distance to hospitals, the white-black gap was significant only for CABG (9.1%; $P<0.001$). The nongeographic component was significant for both conditions (3.4% for AMI and 7.7% for CABG; $P<0.001$) and accounted for nearly the entire gap for CABG. In contrast, hospital geographic proximity was not significant. In regional analyses, white beneficiaries had higher rates of high-quality hospital use in the Northeast (CABG) and South (AMI and CABG), whereas black had higher rates of high-quality hospital use in the Midwest (AMI).

***Conclusions*—**White-black differences in high-quality hospital use were significant for CABG and related to nongeographic factors. Interventions should consider health system and contextual reasons for these disparities. **(*J Am Heart Assoc*. 2019;8:e011964. DOI: 10.1161/JAHA.119.011964.)**

Key Words: coronary artery disease • disparities • hospital • quality of care

Despite marked improvements in treatments for patients with coronary heart disease (CHD),[1] large white-black gaps in CHD quality of care remain.[2–4] The causes of white-black disparities in CHD treatment may be explained in part by differences in the hospitals where black and white patients seek care.[5–11]

Research has shown that black patients with acute myocardial infarction (AMI) or undergoing coronary artery bypass grafting (CABG) surgery are more likely to receive care at low-quality hospitals.[5,8–10] and less likely to receive care at high-quality hospitals[6,7,11] compared with their white peers. Some studies portray a more complex picture, showing that the magnitude of the disparity varies according to acuity of the condition. In particular, gaps may be smaller for AMI, an emergent condition, than for CABG, which is often elective.[7] Yet other studies have shown significant regional variations in hospital quality for heart disease,[12] with potential consequences for disparities.[13] The pathways leading to racial gaps in high- and low-quality hospital use are incompletely understood.

Given the importance of travel distance in hospital choice,[14–16] white-black gaps in the use of hospitals with different quality could be attributable to racial differences in geographic access to high- and low-quality hospitals.

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Accompanying Data S1, Tables S1, S2, and Figures S1, S2 are available at https://www.ahajournals.org/doi/suppl/10.1161/JAHA.119.011964

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Clinical Perspective

What Is New?

- Studies have documented a white-black gap in high-quality hospital use for coronary heart disease, but the contributions of hospital geographic proximity and nongeographic factors to the gap have not been quantified.
- Nationally, the gap was significant for open heart surgery but not for myocardial infarction, and largely due to nongeographic factors.
- Significant regional differences were observed, most notably black patients with myocardial infarction had higher rates of high-quality hospital use in the Midwest.

What Are the Clinical Implications?

- This suggests that disparities in coronary heart disease treatment quality, in particular elective high-risk procedures, are driven by factors above and beyond geography.
- Further studies are needed to understand the relationship between nongeographic factors such as physician referral networks and disparities in high-quality hospital use.

However, evidence shows that blacks are less likely to use high-quality hospitals even when they live closer to these hospitals than whites.[6,11] For instance, black patients with CHD are more likely to bypass top-ranked hospitals for elective cardiac procedures and seek care at lower-quality hospitals located farther from their homes,[7] suggesting that nongeographic factors significantly influence hospital use.

Nongeographic sources of disparities in the quality of hospitals that blacks and whites use are likely complex and can be categorized into patient factors (eg, differences in patients' preferences and attitudes toward particular types of hospitals, or socioeconomic status), provider factors (eg, provider bias or differences in the hospitals to which physicians treating whites and blacks have access), and healthcare system factors (eg, healthcare organizational culture). For the purpose of the current study, we refer to the array of factors influencing hospital choice independent of geographic access as "nongeographic factors."

To date, no study has assessed the contributions of geographic access and nongeographic factors to racial gaps in high- and low-quality hospital use. However, understanding the relative contributions of these factors to the overall gap is likely to be important for more targeted interventions aimed at narrowing these gaps. The current study addresses this shortcoming in the literature by using innovative decomposition methods to quantify the contributions of racial differences in geographic access and nongeographic factors to the white-black gaps in the use of high- and low-quality hospitals for CHD. We hypothesized that both geographic and nongeographic factors contribute to the white-black gaps in high- and low-quality hospital use and that nongeographic factors will have a larger contribution for CABG than for AMI because of the elective nature of CABG surgery. We conducted national analyses, as well as separate analyses for each of the US Census regions.

Methods

Data and Study Sample

Because of the sensitive nature of the data collected for this study, access to the data set requires entering a data use agreement with the Centers for Medicare & Medicaid Services (CMS). Requests from qualified researchers may be sent to the CMS via its Research Data Assistance Center (https://www.resdac.org/).

We used MedPAR files, which contain data on hospital discharges for Medicare fee-for-service beneficiaries, to identify black and white beneficiaries aged 65 or older admitted to the hospital between July 2009 and December 2011 with 2 conditions: AMI (*International Classification of Diseases, Ninth Revision, Clinical Modification* [*ICD-9-CM*] code 410 except 410.x2, subsequent episode of care) and CABG (*ICD-9-CM* codes 36.10–36.19). We excluded beneficiaries with health maintenance organizations or discontinuous part A/B enrollment because of incomplete data; beneficiaries transferred from another hospital, as transfers are influenced by different factors from those determining the initial admission; and beneficiaries who had a previous AMI or underwent coronary revascularization during a 6-month lead-in period for which we had data, as these patients may have different reasons for selecting particular hospitals compared with first-episode patients. We restricted the CABG cohort to cases not occurring in the setting of a primary AMI diagnosis (87%) because these cases were more likely elective. We also limited the sample to beneficiaries living in core-based statistical areas (CBSAs; metropolitan and micropolitan areas anchored by an urban center), excluding rural residents whose hospital choices may differ systematically from those of CBSA residents.

We also excluded beneficiaries who were treated in a CBSA other than their CBSA of residence, as they may have been traveling at the time of their admission.

Finally, we retained only CBSAs with sizeable black and white populations and at least 10 black AMI and CABG cases to ensure the robustness of our comparisons. The final AMI cohort included 35 561 black and 307 813 white beneficiaries admitted to 2681 hospitals in 253 CBSAs.

The final CABG cohort included 3055 black and 40 933 white beneficiaries admitted to 1168 hospitals in 110 CBSAs.

Variables of Interest

Key study variables included patient race and 2 hospital attributes: quality and distance from the hospital to each patient's home. We defined race as black or white, based on Medicare data. We assessed hospital quality using the CMS 30-day risk-standardized AMI mortality rates publicly available on Hospital Compare. CMS did not report mortality measures specific to CABG during the study period. Thus, we used the AMI measure for both conditions, since it may in fact reflect a hospital's overall quality of care for CHD. We identified low-quality hospitals as hospitals ranking in the top quintile and high-quality hospitals as hospitals ranking in the bottom quintile of the mortality distribution for all hospitals in the AMI cohort. Hospitals with mortality rates in the middle 3 quintiles were classified as medium-quality hospitals. For consistency, we applied the same rankings for each hospital in both cohorts. We measured home-to-hospital distance as the straight-line distance, using patients' home zip code centroids and hospitals' street addresses. In addition, we performed sensitivity analyses using different cutoffs for high and low quality at the 15th and 25th percentiles of the mortality distribution.

Other patient-level variables used to describe our study sample included age, sex, and a comorbidity index[17] obtained from the hospital claims data.

Regression Models

Since patients living in urban areas have numerous hospitals to choose from, our analyses employed the conditional logit regression model.[18] In this model, the probability that a patient uses a particular hospital is a function of the attributes of all the hospitals to which the patient could have reasonably been admitted. Thus, the model explicitly accounts for the attributes of the hospital chosen by the patient as well as those of hospitals not chosen. This is accomplished by fitting the model to a file that includes, for each patient, information on each hospital that the patient could have used; an indicator variable identifies the hospital actually used. Further, patient race does not appear as a main effect in this model; rather, it is interacted with the hospital attributes to assess whether the effects of distance and hospital quality on the likelihood of using a hospital differ between blacks and whites.

To estimate the models, we first developed the set of hospitals to which each patient could have been admitted (ie, "hospital choice sets"), defined as all hospitals available within 100 miles of patients' home. Although some of the more distant hospitals in these choice sets may have never been used by patients, in the conditional logit model, hospitals never used do not affect estimates.[18]

We modeled the probability that a patient uses a particular hospital as a function of quality (high, medium, and low) and the home-to-hospital distance for all hospitals in the choice set. Because the relationship between distance and hospital use is nonlinear, we specified distance using a binary indicator variable for the closest hospital in each choice set and a set of indicator variables for incremental distance categories (ie, 0–2, 2–4, 4–6, 6–8, 8–10, 10–15, 15–30, 30–60, and >60 miles from the closest hospital). By interacting race with hospital attributes, we effectively estimated distinct coefficients for blacks and whites.

Decompositions

We used the regression estimates to decompose the overall gap between blacks and whites in high- and low-quality hospital use into 2 components: (1) racial differences in the geographic availability of high- and low-quality hospitals and (2) racial differences in nongeographic factors influencing which hospitals patients use. We conceptualized the first component as the difference in the probabilities that black patients would use a high-quality (or a low-quality) hospital in the hypothetical scenario where they face the sets of hospitals available to white patients versus when they face their own choice sets. We conceptualized the second component as the difference in the probabilities that white patients and black patients would use a high-quality (or a low-quality) hospital if they both faced white patients' choice sets.

To operationalize these concepts, we employed the estimated model coefficients and the hospital choice sets for black and white patients to calculate the predicted probabilities that a black patient would use each hospital in each black patient's choice set, that a black patient would use each hospital in each white patient's choice set, and that a white patient would use each hospital in each white patient's choice set. Predicted probabilities were then summed across hospitals within the same quality level and averaged by race. (Decomposition details are provided in Data S1.)

We developed standard errors for the predicted probabilities and for differences between predicted probabilities using the clustered bootstrap,[19] where the clusters were the CBSAs. To test the statistical significance of racial differences in probabilities of hospital use, we employed t-statistics constructed using the bootstrap standard errors.

We conducted analyses for the United States as a whole and for each Census region separately.

The study was approved by the UCLA institutional review board, and a waiver of consent was obtained.

Table. Characteristics of Black and White Medicare Beneficiaries Admitted for AMI or CABG at US Hospitals During 2009–2011

Patient Characteristic	AMI		CABG	
	White (N=307 813)	Black (N=35 561)	White (N=40 933)	Black (N=3055)
Region*				
Northeast	25.6%	17.8%	20.2%	14.2%
South	39.7%	48.5%	46.5%	56.5%
Midwest	22.7%	26.2%	24.6%	24.0%
West	12.0%	7.4%	38.7%	5.3%
Age group (y), %*				
65–69	11.9	23.0	19.4	32.6
70–74	14.8	17.7	27.9	29.5
75–79	17.1	17.7	26.3	22.3
80–84	20.3	16.5	18.9	12.1
85+	35.9	25.2	6.7	3.2
Female, %*	52.0	60.3	30.7	46.8
Comorbidity index,† mean (SD)*	6.9 (8.1)	8.3 (8.4)	5.1 (7.1)	5.9 (7.6)
High-quality hospital is closest or second-closest hospital, %‡	48.2	48.3	49.9	45.0
Admitted to a high-quality hospital, %*	34.8	32.4	39.0	29.9
Low-quality hospital is closest or second-closest hospital, %§	27.0	24.1	23.1	24.6
Admitted to a low-quality hospital, %	11.2	11.0	9.7	10.2

AMI indicates acute myocardial infarction; CABG indicates coronary artery bypass grafting surgery.
*P<0.001 for all white-black comparisons.
†The comorbidity index represents a weighted summary of 30 prevalent comorbidities identified from secondary diagnoses present at hospital discharge. The index is calculated using a previously published methodology.[17]
‡P<0.001 for the CABG cohort only.
§P<0.001 for the AMI cohort only.

Results

Descriptive Data

For both conditions, blacks were younger, more often female, and had higher comorbidity compared with whites (Table). For AMI, similar proportions of white and black beneficiaries had a high-quality hospital as the closest or second-closest hospital. However, a slightly higher proportion of white beneficiaries was admitted to a high-quality hospital (Table). On the other hand, a higher proportion of white beneficiaries had a low-quality hospital as the closest or second-closest hospital, but similar proportions of white and black beneficiaries were admitted to these hospitals (Table). For CABG, higher proportions of white beneficiaries had a high-quality hospital as the closest or second-closest hospital and were admitted to high-quality hospitals (Table). Proportions of white and black beneficiaries having a low-quality hospital as the closest or second-closest hospital, and admitted to a low-quality hospital, were similar (Table). Study hospital characteristics are summarized in the online supplement (Table S1). Of note, hospitals in the CABG cohort represent a subset of the hospitals in the AMI cohort, which are larger, more likely teaching tertiary care centers with cardiac surgery capabilities.

Regression Results

The conditional logit model estimates revealed that, as expected, both blacks and whites were more likely to use the closest hospital and that increasing distance was negatively associated with using a hospital. The effects of distance on the probability of hospital use were similar across races and study conditions (Table S2). With respect to quality, both white and black beneficiaries were more likely to use high- and medium-quality hospitals compared with low-quality hospitals (Table S2).

Decompositions

Figures 1 and 2 present results from the decompositions of the national white-black gap in the use of high- and low-quality hospitals for AMI and CABG, where the gap is the difference between the white and black probabilities of use.

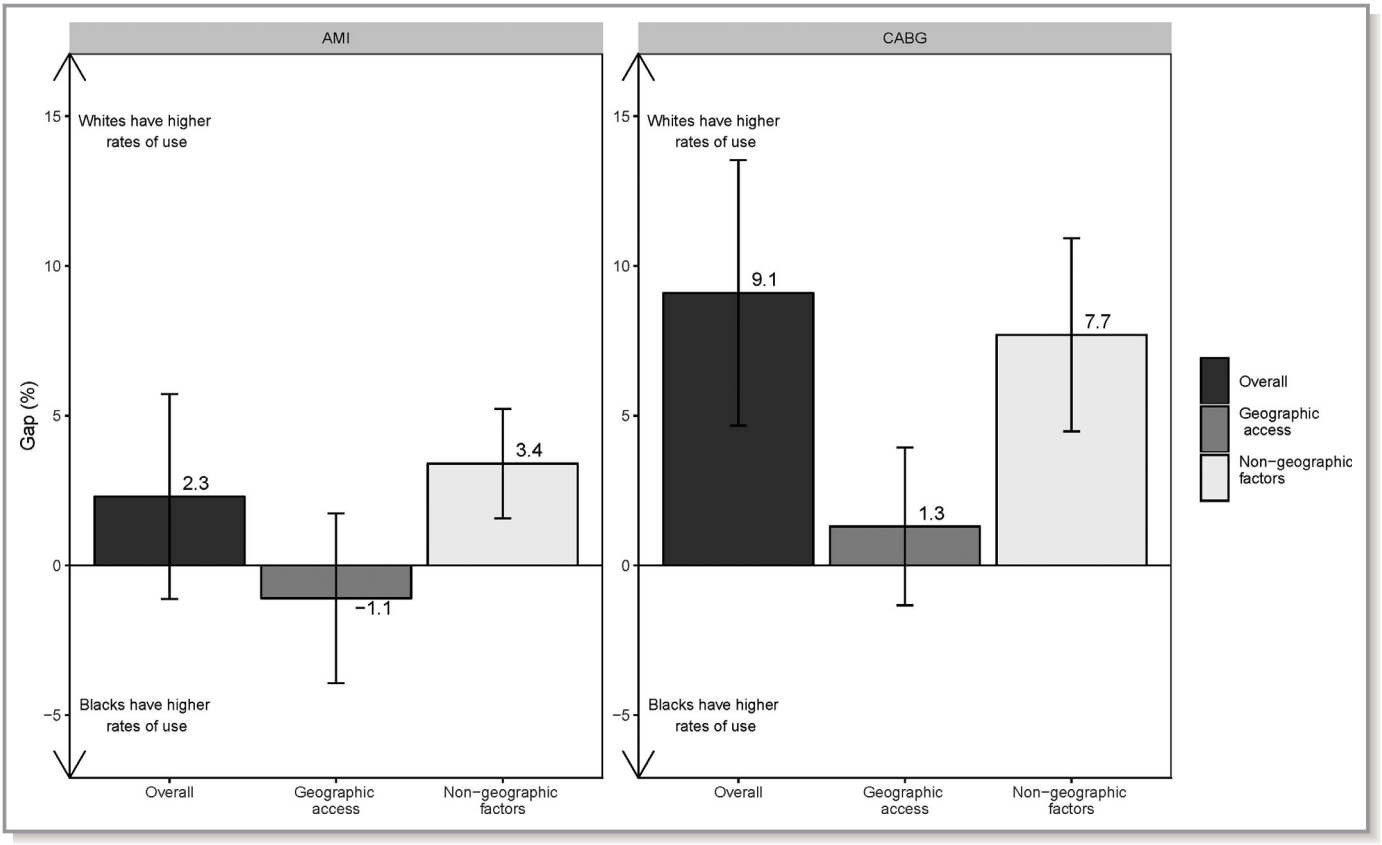

Figure 1. The national white-black gap in high-quality hospital use for acute myocardial infarction (AMI) and coronary artery bypass grafting (CABG) surgery.

Nationally, the white-black gap in high-quality hospital use was positive for both study conditions (ie, white beneficiaries had higher use), but it was statistically significant only for CABG (2.3%, P=0.18 for AMI; 9.1%, P<0.001 for CABG). However, the component attributable to racial differences in nongeographic factors was positive and significant for both conditions (3.4%, P<0.001 for AMI; 7.7%, P<0.001 for CABG), meaning that, given similar geographic proximity of high-quality hospitals, white beneficiaries would be, on average, more likely than black beneficiaries to use those hospitals. Further, nearly all of the CABG gap was due to the nongeographic component. On the other hand, the component attributable to racial differences in the geographic availability of high-quality hospitals was small and not significant for either condition (−1.1%, P=0.44 for AMI; and 1.3%, P=0.31 for CABG).

The overall gap in low-quality hospital use was small and not statistically significant for either condition (0.3%, P=0.79 for AMI; −0.5%, P=0.40 for CABG) (Figure 2). In the case of AMI, both gap components were significant, although they worked in opposite directions, showing that, although white beneficiaries had more low-quality hospitals closer to their homes, they were no more likely to use low-quality hospitals than black beneficiaries were, because of nongeographic factors (eg, better referrals).

While not shown, given the lower probability of high-quality hospital use and similar probability of low-quality hospital use, black beneficiaries had a higher probability of medium-quality hospital use than did white beneficiaries (Table S2).

Additional decompositions performed by US Census region are presented in Figures 3 and 4 and Figures S1 and S2. For AMI, white beneficiaries had a significantly higher probability of high-quality hospital use in the South primarily because of differences in nongeographic factors (Figure 3). In the Midwest, however, black beneficiaries had a significantly higher probability of high-quality hospital use for AMI because of better geographic proximity (Figure 3). For CABG, white beneficiaries had a significantly higher probability of high-quality hospital use in the Northeast and South regions (Figure 4). The component attributable to geographic proximity was uniformly not significant, while the component attributable to differences in nongeographic factors was significant in 3 of 4 regions, favoring whites (Figure 4).

For low-quality hospitals (Figures S1 and S2), the overall gap and the components attributable to differences in

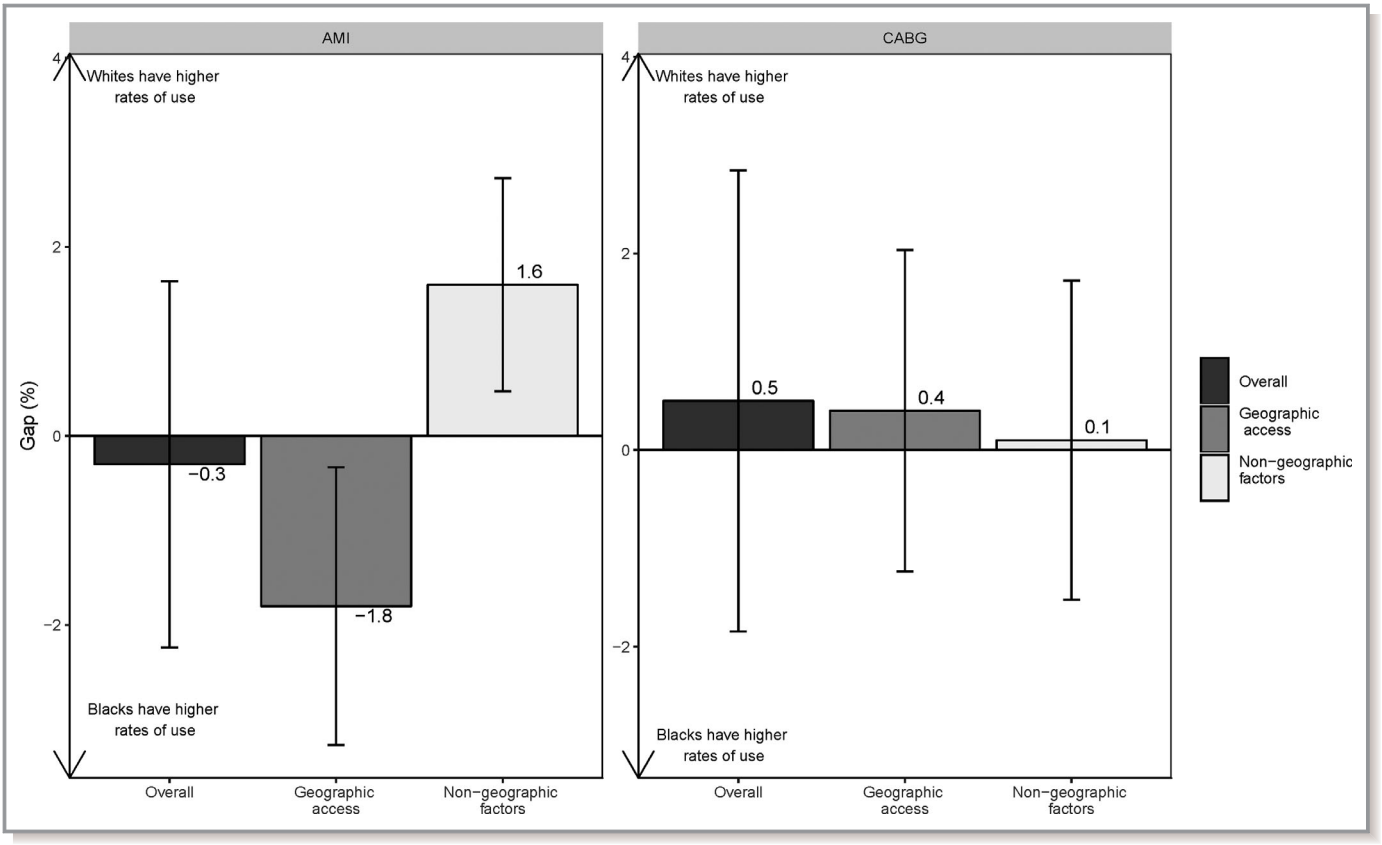

Figure 2. The national white-black gap in low-quality hospital use for acute myocardial infarction (AMI) and coronary artery bypass grafting (CABG) surgery.

geographic and nongeographic factors were largely not significant, except for the Midwest, where black beneficiaries had a lower probability of low-quality hospital use because of lower geographic proximity of low-quality hospitals.

Sensitivity analyses for the high- and low-quality hospital definitions yielded gaps and components of similar magnitude and direction.

Discussion

Among fee-for-service Medicare beneficiaries with CHD, we found that whites lived overall closer to high-quality hospitals and were more likely to be admitted to these hospitals than were blacks, although differences were significant only for CABG.

Moreover, we found that white-black differences in high-quality hospital use for CABG were primarily related to differences in nongeographic factors, meaning that given similar geographic proximity, white beneficiaries were more likely to use high-quality hospitals. On the other hand, black beneficiaries had higher probabilities of medium-quality hospital use, and white-black differences in low-quality hospital use were not significant for both conditions. Distinct patterns emerged in regional analyses. White beneficiaries had a higher probability of high-quality hospital use in the Northeast and South (although the results did not reach statistical significance for the overall AMI gap in the Northeast), mainly associated with differences in nongeographic factors, while black beneficiaries with AMI had a higher probability of high-quality hospital use in the Midwest, mainly related to better geographic availability of high-quality hospitals. Regional gaps in low-quality hospital use were not significant except, again, in the Midwest, where black beneficiaries had a lower probability of low-quality hospital use.

The current findings build on earlier work describing white-black disparities in hospital quality for CHD treatment, yet differ from prior work in important ways. First, in contrast to prior analyses,[6,20,21] this study found no significant racial gaps in high-quality hospital use for AMI. Second, we found no significant disparities in low-quality hospital use for either condition. The divergent results may have several explanations, including differences in sample size (prior studies used fewer metro areas and patients or incorporated nonmetro areas) or differences in hospital quality definitions (eg, mortality, process of care, or reputation-based measures).

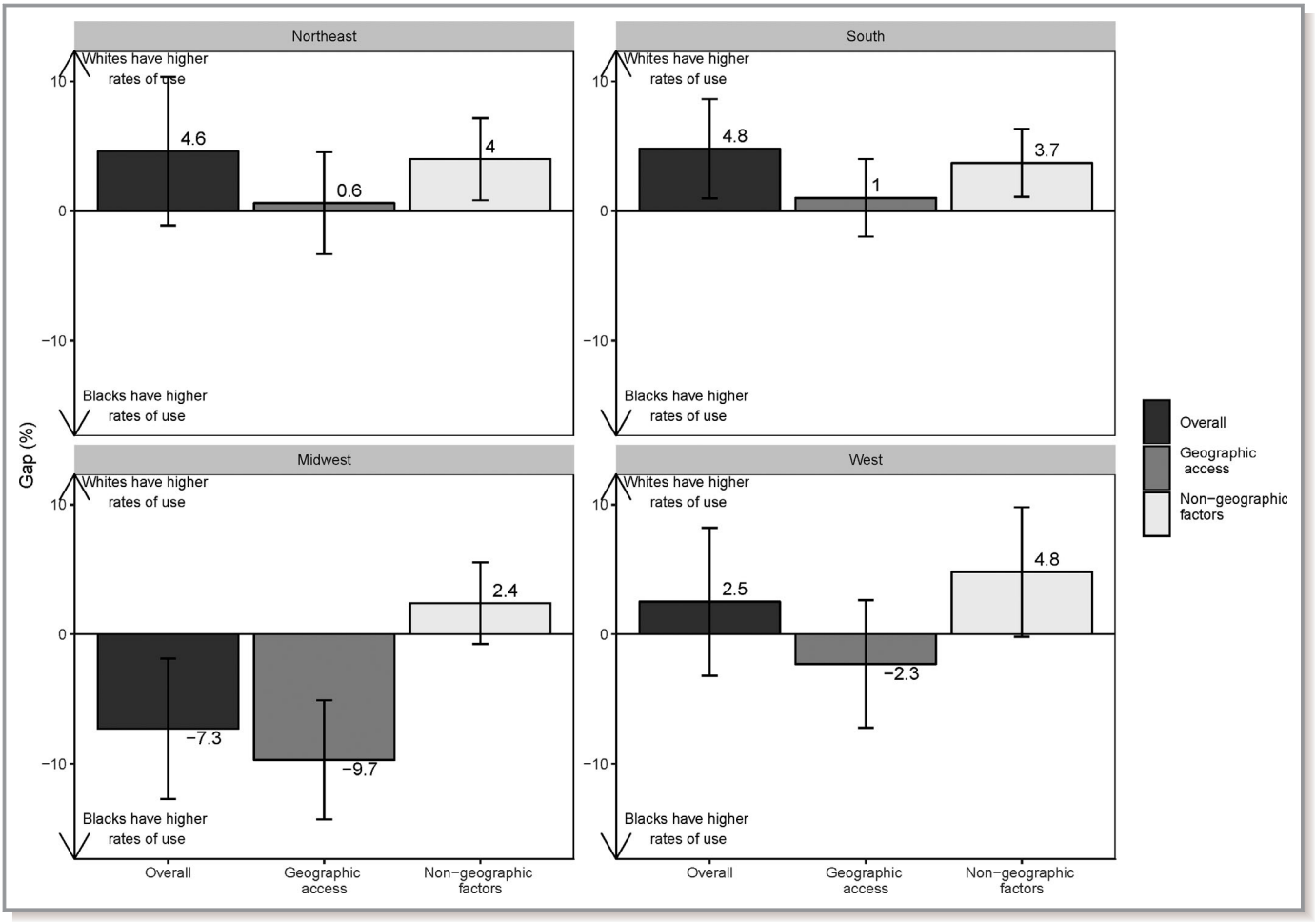

Figure 3. Regional white-black gaps in high-quality hospital use for acute myocardial infarction (AMI).

Our results also suggest that national-level analyses of disparities in high- and low-quality hospital use may mask important geographic variations. For example, the finding that the overall gap in high-quality use for AMI is not significant misses the fact that patterns of use differ strikingly in the Midwest, where blacks have higher rates of use than whites related to better geographic access, and the South, where whites have higher rates of use in association with differences in nongeographic factors influencing hospital use. However, in the case of CABG, whites had higher rates of high-quality hospital use across all regions (albeit significant only in the Northeast and South), mainly related to nongeographic factors. Taken together, the findings from regional analyses seem to suggest that a more geographically targeted, condition-specific approach is needed for interventions to reduce CHD disparities.

The most striking finding of this analysis is the relatively large and significant white-black gap in high-quality hospital use for CABG, which stands in sharp contrast to the nonsignificant gap for AMI. Moreover, decomposition results show that the gap is almost entirely attributable to white-black differences in nongeographic factors. Unlike AMI, which requires urgent treatment at the closest hospital, elective CABG surgery is a planned procedure. Thus, healthcare referral systems, social contextual factors, and patient characteristics potentially influencing hospital choice are likely to play a larger role in what types of hospitals patients use. These factors may influence high-quality hospital use for blacks and whites differently.

To begin with, blacks and whites may have access to physicians practicing in distinct referral networks. This explanation is supported by prior research showing that the care of black patients is concentrated among a small number of physicians who report lower access to hospitals and advanced technologies.[22,23] Further, a recent analysis of physician networks for cardiac surgery showed that networks serving communities with high and low black populations have different characteristics.[24] In particular, physicians in networks serving predominantly blacks are more isolated, with potentially negative consequences for referral access. Altogether, this

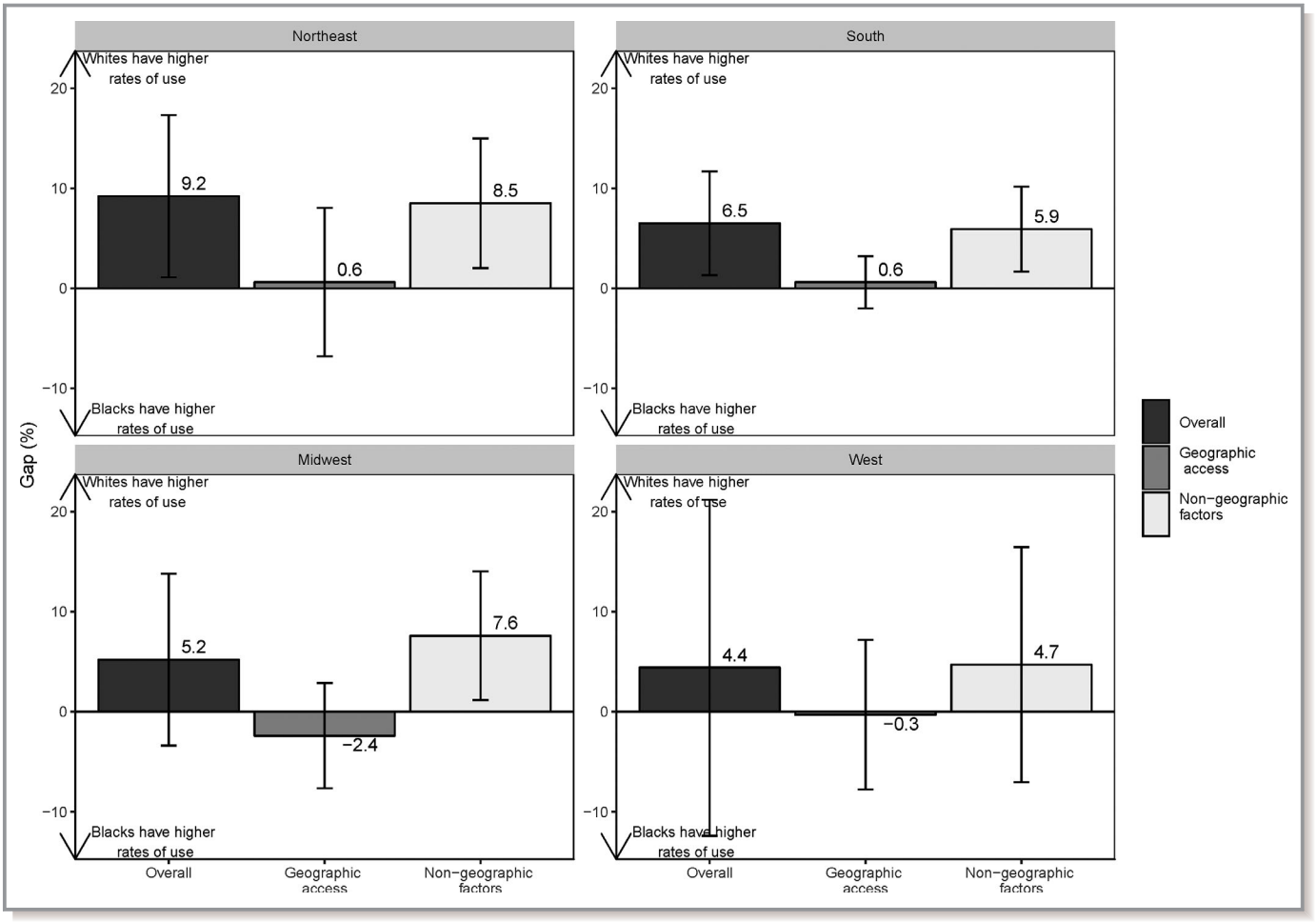

Figure 4. Regional white-black gaps in high-quality hospital use for coronary artery bypass grafting (CABG) surgery.

body of evidence suggests that physician networks may be a driver of the nongeographic white-black gap component and ultimately lead to disparities in high-quality hospital use.

In addition, black and white patients may prefer to use hospitals with different attributes. For example, studies have shown that black beneficiaries are more likely to use teaching hospitals compared with their white peers.[25,26] Furthermore, blacks may have higher levels of distrust in the healthcare system because of experience with prior discrimination.[27] As a result, blacks may be less willing to seek care at particular institutions that are perceived as practicing unjust care toward people of color, and may prefer to use hospitals they assume will be more sensitive to their needs and more devoted to their welfare.[28,29] Therefore, unobserved racial differences in hospital preferences might contribute to the nongeographic component of the gap.

Finally, differences in medical decision making may also contribute to the observed gap. Provider bias and stereotyping[30,31] and differences in patient-provider communication[32] could lead to treatment misconceptions and reinforce distrust in healthcare institutions, ultimately contributing to differences in the referral process. However, whether these factors influence the racial gap in high-quality hospital use remains unclear. While prior analyses suggest that black patients are more often treated by lower-quality cardiac surgeons,[33–35] the underlying reasons for these differences (eg, differences in admitting privileges, physician assessments of hospital quality, bias, or perceptions of patient preferences) are not known.

Limitations

Several study limitations merit discussion. First, we have not directly examined black and white patients' choices for hospital care. Rather, we are describing patterns of high- and low-quality hospital use.

In addition, while this type of decomposition is commonly used in econometrics and has been previously employed to explain health disparities,[36,37] it does rely on assumptions. Specifically, the method assumes that, under the hypothetical scenario where black patients are faced with white patients' hospital choices, the contribution of

unexplained (nongeographic) factors influencing the gap (eg, black patient preferences and access to referral systems) remains constant (ie, as observed when patients face their actual choices).

Second, analyses were based on hospital claims data, which lack information on patient preferences and provider referrals. Although we could not explore the specific provider and patient factors potentially contributing to the nongeographic component of the gap, our findings strongly suggest that nongeographic factors are primarily responsible for the white-black gaps in high-quality hospital use and can help focus future interventions on these types of factors.

Third, data for this study (2009–2011) may not reflect the current state of disparities in CHD care. However, several other studies published as recently as 2016 continue to show black-white disparities in coronary care.[38] Further, CMS did not report CABG-specific hospital-level outcome measures at the time of this study, leading us to use the AMI hospital-level mortality measure to rank hospital quality for both cohorts. It is possible that using the AMI measure for both conditions led to potential misclassification in the setting of discordant performance for AMI and CABG. The assumption that the quality of care for different CHD conditions is correlated at the hospital level should be further tested.

Fourth, in regional analyses, some components did not reach statistical significance, suggesting that analyses may have been underpowered because of the smaller samples, particularly in the West. Fifth, the current analysis is limited to Medicare beneficiaries aged 65 and older. Since age and insurance are both known to influence hospital choice,[39,40] findings may not be generalizable to the younger populations or to other vulnerable categories (eg, the uninsured).

Finally, the use of straight-line distances has its limitations, as travel conditions may be different for urban areas with varied population density and infrastructure. To lessen this issue, our study included only urban (metropolitan) areas. Further, other studies have used straight-line distance to approximate travel distance to hospitals. More granular analyses may be needed to capture local variations in travel conditions.

Conclusions

Overall, we found racial gaps in the use of high-quality hospitals for CHD, in particular for elective CABG. With few exceptions (ie, the Midwest), these gaps were primarily related to factors above and beyond geographic access. To address disparities, a better understanding of what underlies racial differences in nongeographic factors influencing hospital use is needed. Furthermore, given the regional variations shown by our analyses, more granular market- or metro area–level analyses may be better suited to identify the contributions of geographic and nongeographic (eg, system or patient) factors to the racial gap in high-quality hospital use for CHD.

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Disclosures

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Supplemental Material

Data S1.

Supplemental Methods

Decompositions

As discussed in the Methods section of the paper, our goal was to decompose the overall gap between whites and blacks in the use of hospitals of varying quality levels into two components: (1) racial differences in geographic access to hospitals of different quality levels and (2) racial differences in hospital choice behavior. We conceptualize the first component as the difference in the probabilities that black patients would use a high-quality (or a low-quality) hospital in the hypothetical scenario where they face white patients' choice sets versus when they face their own choice sets. We conceptualize the second component as the difference in the probabilities that white patients and black patients would use a high-quality (or a low-quality) hospital if they both faced white patients' choice sets. In this Appendix, we provide details on how we operationalize these concepts to decompose the overall white-black gap in high-quality hospital use. The decomposition of the overall gap in low-quality hospital is exactly analogous.

We index patients using the subscript *i* and use *W* to denote the set of white patients and *B* to denote the set of black patients. Thus $i \epsilon W$ means that patient *i* is white and $i \epsilon B$ means that patient *i* is black. We denote the total numbers of white and black patients by N_w and N_b, respectively. We use S_i to denote patient *i*'s "choice set" of hospitals and note that S_i is composed of a subset of high-quality hospitals, which we denote as H_i; a subset of medium-quality hospitals, M_i; and a subset of low-quality hospitals, L_i. In set notation, we can write: $S_i = H_i \cup M_i \cup L_i$.

As described in the Methods section, we estimated conditional logit models that modeled the probability that a patient uses a particular hospital as a function of the quality of all the hospitals in the patient's choice set (indicator variables for high, medium, and low) and the home-to-hospital distance for all the hospitals in the choice set. Because the distance from a patient's home to the closest hospital varies across patients and because the relationship between distance and hospital choice is nonlinear, we specified distance using a binary indicator variable for the closest hospital in each patient's choice set and a set of indicator variables for incremental distance categories (0--2, 2-4, 4-6, 6-8, 8-10, 10-15, 15-30, 30-60 and >60). We denote the vector of attributes (i.e., the indicators for quality and distance) for hospital *h*, as they pertain to patient *i*, as $X_{i,h}$. As mentioned in the paper, when we estimated the models we interacted patient race with the hospital attributes. Thus we effectively estimated distinct vectors of regression coefficients for white and black patients, which we denote as $\hat{\beta}_w$ and $\hat{\beta}_b$, respectively.

According to a standard formula for conditional logit models,[1] the predicted probability, $\hat{p}_{i,h}$, that white patient *i* uses hospital *h* in her choice set is given by:

$$\hat{p}_{i,h} = \frac{exp\ (\hat{\beta}_w X_{i,h})}{\sum_{k \epsilon S_i} exp\ (\hat{\beta}_w X_{i,k})}$$

for $i \epsilon W$. To obtain the predicted probability that patient *i* uses a high-quality hospital, $\hat{P}_i(High)$, we sum the predicted probabilities, $\hat{p}_{i,h}$, across the high-quality hospitals in patient *i*'s choice set. Therefore, we can write:

$$\hat{P}_i(High) = \sum_{h \epsilon H_i} \hat{p}_{i,h}$$

for $i \epsilon W$.

Finally, to obtain the predicted probability that white patients use a high-quality hospital when they face white patients' choice sets (i.e., their own choice sets), $\hat{P}_w(High|white\ choice\ sets)$, we average $\hat{P}_i(High)$ across all the white patients in the study:

$$\hat{P}_w(High|white\ choice\ sets) = \frac{\sum_{i \epsilon W} \hat{P}_i(High)}{N_w}$$

This is the first quantity we need for our decomposition.

Using analogous reasoning, the predicted probability, $\hat{p}_{i,h}$, that black patient *i* uses hospital *h* in her choice set is given by:

$$\hat{p}_{i,h} = \frac{exp\ (\hat{\beta}_b X_{i,h})}{\sum_{k \epsilon S_i} exp\ (\hat{\beta}_b X_{i,k})}$$

for $i \epsilon B$. To obtain the predicted probability that patient *i* uses a high-quality hospital, $\hat{P}_i(High)$, we sum the predicted probabilities, $\hat{p}_{i,h}$, across the high-quality hospitals in patient *i*'s choice set, as follows:

$$\hat{P}_i(High) = \sum_{h \epsilon H_i} \hat{p}_{i,h}$$

for $i \epsilon B$.

Finally, to obtain the predicted probability that black patients use a high-quality hospital when they face black patients' choice sets (i.e., their own choice sets), $\hat{P}_b(High|black\ choice\ sets)$, we average $\hat{P}_i(High)$ across all the black patients in the study:

$$\hat{P}_b(High|black\ choice\ sets) = \frac{\sum_{i \epsilon B} \hat{P}_i(High)}{N_b}$$

This is the second quantity we need for our decomposition.

The third quantity we need for our decomposition is the predicted probability that black patients use a high-quality hospital when they face white patients' choice sets rather than their own choice sets. This is the trickiest quantity to obtain, because it requires taking the white patients, each of which comes with her own choice set, and assigning the probabilities of using each hospital in a choice set as if the patient were black rather than white. (This is what it means for black patients to face white patients' choice sets.) In practice, this is accomplished by calculating the predicted probabilities, $\hat{p}_{i,h}$, using white patients' choice sets, but using the black coefficients, $\hat{\beta}_b$, in place of the white coefficients. Thus we calculate:

$$\hat{p}^*_{i,h} = \frac{exp\ (\hat{\beta}_b X_{i,h})}{\sum_{k \epsilon S_i} exp\ (\hat{\beta}_b X_{i,k})}$$

for $i \epsilon W$. The fact we sum over the choice sets for $i \epsilon W$ is the key that indicates we are using white patients' choice sets. We also modify the notation, adding an asterisk superscript to $\hat{p}^*_{i,h}$ in order to denote that these are predicted probabilities for black patients facing white choice sets.

To obtain the predicted probability that black patient *i* uses a high-quality hospital, $\hat{P}_i^*(High)$, we sum the predicted probabilities, $\hat{p}_{i,h}^*$, across the high-quality hospitals in the choice set, as follows:

$$\hat{P}_i^*(High) = \sum_{h \epsilon H_i} \hat{p}_{i,h}^*$$

for $i \epsilon W$.

Finally, to obtain the predicted probability that black patients use a high-quality hospital when they face white patients' choice sets, $\hat{P}_b^*(High|white\ choice\ sets)$, we average $\hat{P}_i^*(High)$ across all the white choice sets in the study:

$$\hat{P}_b^*(High|white\ choice\ sets) = \frac{\sum_{i \epsilon W} \hat{P}_i^*(High)}{N_w}$$

This is the third quantity we need for our decomposition.

Now we are ready to decompose the overall white-black gap in high-quality hospital use, $\Delta(white - black)$. As we have defined it, the overall gap is the difference between the probability that white patients use a high-quality hospital and the probability that black patients use a high-quality hospital when each race faces its own choice sets. Thus we can write:

$$\Delta(white - black) = \hat{P}_w(High|white\ choice\ sets) - \hat{P}_b(High|black\ choice\ sets)$$

Adding and subtracting the quantity $\hat{P}_b^*(High|white\ choice\ sets)$ and rearranging terms, we obtain:

$$\Delta(white - black) = \{\hat{P}_b^*(High|white\ choice\ sets) - \hat{P}_b(High|black\ choice\ sets)\} + \{\hat{P}_w(High|white\ choice\ sets) - \hat{P}_b^*(High|white\ choice\ sets)\}$$

As desired, the first term on the right side of this equation captures the racial differences in geographic access to high-quality hospitals, whereas the second term captures the racial differences in hospital choice behavior. For both components positive values favor whites, that is, positive values indicate that white patients are more likely than blacks to use high-quality hospitals.

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Table S1. Characteristics of hospitals treating black and white Medicare beneficiaries admitted with AMI or undergoing CABG during 2009-2011.

Characteristic	AMI (N=2,570)	CABG (N=1,006)
Quality		
% High Quality	21.3%	27.7%
% Medium Quality	59.6%	56.6%
% Low quality	19.0%	15.7%
Revascularization services		
PCI and CABG	44.5%	N/A
PCI only	25.4%	N/A
None	30.0%	N/A
Teaching status		
Major	10.1%	20.8%
Minor	21.1%	28.7%
None	68.3%	49.9%
Ownership		
For-profit	17.7%	17.9%
Private not-for-profit	67.3%	69.7%
Government non-federal	14.4%	11.8%
Bed size		
<100	21.3%	2.1%
100-299	49.3%	42.1%
300-499	18.8%	32.6%
≥ 500	10.1%	22.6%

Table S2. Model coefficients, standard errors and statistical significance.

Model variables†	AMI		CABG	
	Estimate	Robust SE	Estimate	Robust SE
White*high quality hospital	0.79*	0.079	0.68*	0.14
White*medium quality hospital	0.34*	0.076	0.11	0.12
Black*high quality hospital	0.42*	0.083	0.35***	0.18
Black*medium quality hospital	0.19***	0.088	0.29	0.18
White*0-2 miles	-0.18*	0.048	-0.06	0.08
White*2-4 miles	-0.77*	0.062	-0.41*	0.07
White*4-6 miles	-1.28*	0.087	-0.77*	0.11
White*6-8 miles	-1.72*	0.127	-1.07*	0.11
White*8-10 miles	-2.26*	0.127	-1.36*	0.12
White*10-15 miles	-2.97*	0.142	-2.01*	0.12
White*15-30 miles	-4.19*	0.138	-3.01*	0.15
White*30-60 miles	-5.97*	0.128	-4.33*	0.15
White*60-100 miles	-7.86*	0.086	-6.08*	0.16
Black*0-2 miles	-0.20***	0.100	-0.02	0.14
Black *2-4 miles	-0.92*	0.097	-0.35**	0.13
Black *4-6 miles	-1.44*	0.140	-0.74*	0.16
Black *6-8 miles	-1.88*	0.193	-1.00*	0.14
Black *8-10 miles	-2.51*	0.199	-1.29*	0.11
Black *10-15 miles	-3.18*	0.224	-2.24*	0.17
Black *15-30 miles	-4.61*	0.194	-3.22*	0.24
Black *30-60 miles	-6.14*	0.147	-4.63*	0.19
Black *60-100 miles	-7.97*	0.131	-5.81*	0.29

†Omitted (reference) categories were white*low quality hospital and black*low quality hospital for quality, and white*closest hospital and black*closest hospital for distance categories

*p<.001; **p<.01; ***p<.05

Figure S1.

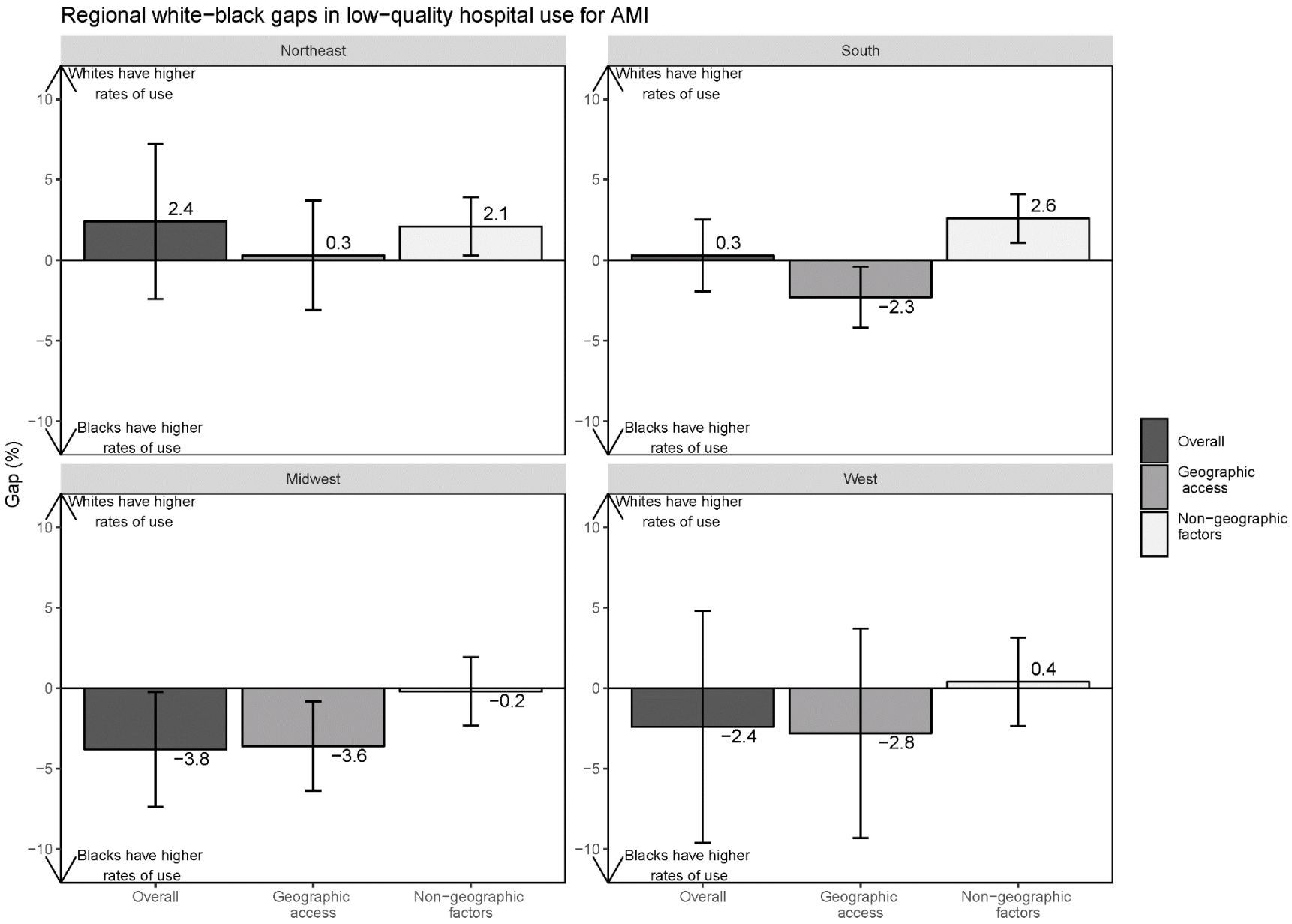
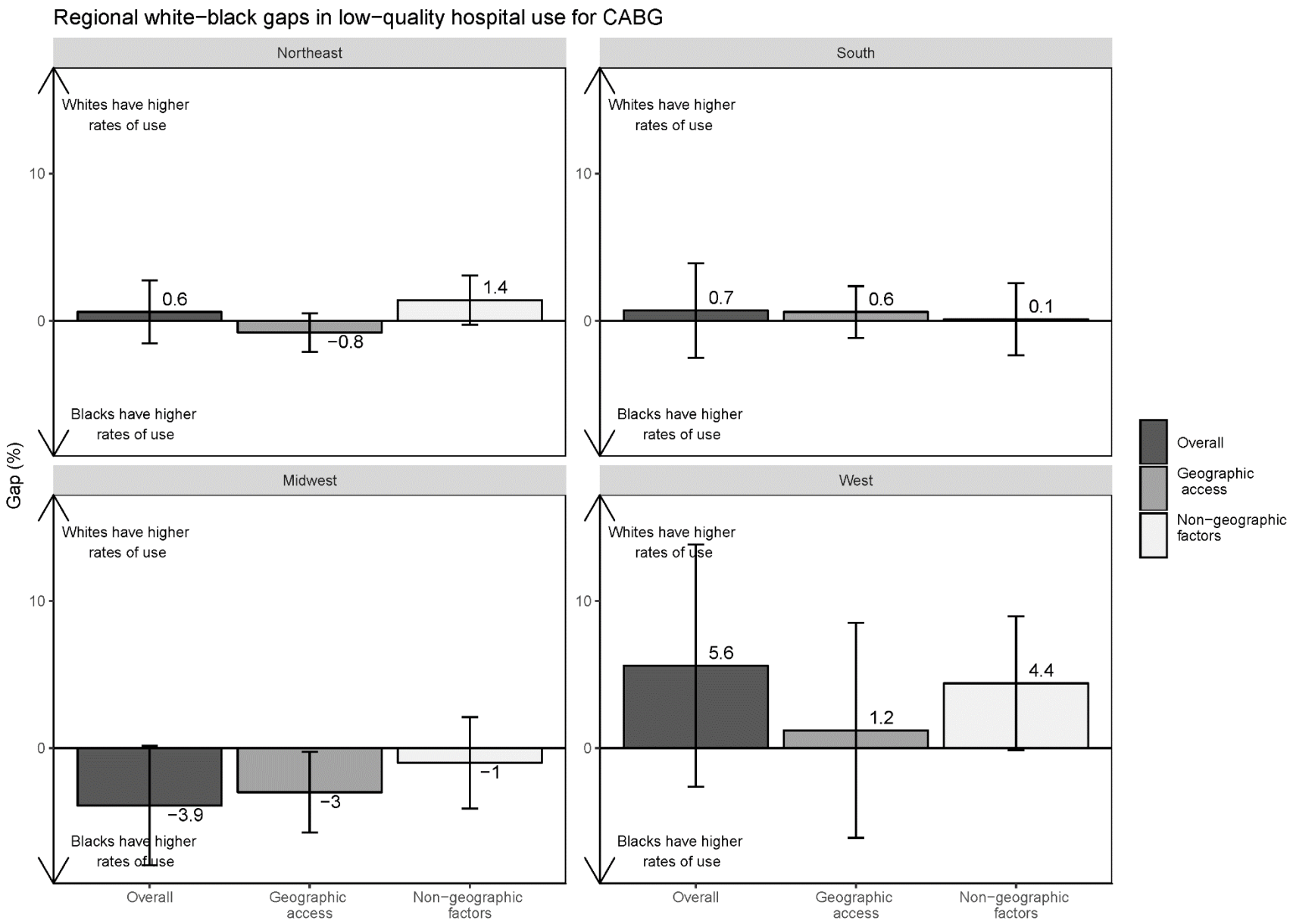

Regional white−black gaps in low−quality hospital use for AMI
Northeast
South
Midwest
West
Whites have higher rates of use
Blacks have higher rates of use
Gap (%)
10
5
0
−5
−10
2.4
0.3
2.1
0.3
−2.3
2.6
−3.8
−3.6
−0.2
−2.4
−2.8
0.4
Overall
Geographic access
Non−geographic factors

Figure S2.


Regional white−black gaps in low−quality hospital use for CABG
Northeast
South
Midwest
West
Whites have higher rates of use
Blacks have higher rates of use
Gap (%)
10
0
0.6
−0.8
1.4
0.7
0.6
0.1
−3.9
−3
−1
5.6
1.2
4.4
Overall
Geographic access
Non−geographic factors