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The Role of Decision Support Systems in Attenuating Racial Biases in Healthcare Delivery

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Abstract. Although significant research has examined how technology can intensify racial and other outgroup biases, limited work has investigated the role information systems can play in abating them. Racial biases are particularly worrisome in healthcare, where underrepresented minorities suffer disparities in access to care, quality of care, and clinical outcomes. In this paper, we examine the role clinical decision support systems (CDSS) play in attenuating systematic biases among black patients, relative to white patients, in rates of amputation and revascularization stemming from diabetes mellitus. Using a panel of inpatient data and a difference-in-difference approach, results suggest that CDSS adoption significantly shrinks disparities in amputation rates across white and black patients—with no evidence that this change is simply delaying eventual amputations. Results suggest that this effect is driven by changes in treatment care protocols that match patients to appropriate specialists, rather than altering within physician decision making. These findings highlight the role information systems and digitized patient care can play in promoting unbiased decision making by structuring and standardizing care procedures.

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Keywords: healthcare bias • racial bias • electronic health records • clinical decision support systems • amputation; protocols

Introduction

Racial bias is an endemic problem. In the United States, equally qualified African Americans are less likely to be called back for job interviews (Bertrand and Mullainathan 2004), receive smaller raises for equivalent work (Castilla 2008), and are more likely to be incarcerated for similar crimes (Abrams et al. 2012). Even in the emerging on-demand economy, where digitally mediated interactions are expected to ameliorate such concerns, minorities experience decreased access to housing (Edelman and Luca 2014) and transportation (Ge et al. 2016). Historic attempts to eliminate such biases were multifaceted, ranging from sensitizing and training decision makers (Correll et al. 2007), to whitewashing (Goldin and Rouse 2000), to increasing contact between the decision maker and social outgroups (Beaman et al. 2009). More recently, recommendation systems have been investigated, the intuition being that digital systems will be unencumbered by the ascriptive biases of their coders (Cowgill 2018). Yet, concerns with this approach have come to the fore (Hosanagar 2019, O'Neil 2016). Received research indicates that algorithms are more likely to send police to minority neighborhoods (Angwin et al. 2016), cast nurses as women (Caliskan et al. 2017), recommend advertisements for background checks when black names are searched on the internet (Sweeney 2013), and advertise high-paying jobs to men (Datta et al. 2015).

One way around such concerns that remains underexplored in the voluminous literature on digitization and bias is the use of protocols and checklists to standardize decision making. This absence of work is striking, given the degree to which protocols are used across a variety of industries (e.g., aviation, healthcare, defense). Unlike recommendation systems, which provide decision makers with a set of suggestions that may be subject to confirmation biases or disregarded altogether (Cowgill 2018), protocols create a structured information-gathering process (Arriaga et al. 2013, National Transportation Safety Board 2010). Moreover, such protocols ensure that decision makers adhere to consistent steps and guidelines when gathering information, thereby formalizing the decision-making process and reducing subjectivity.

Protocols are especially useful in contexts like medicine, where decision making is inherently complex (Gawande 2010). It is therefore no surprise that standardized decision-making protocols and adherence to guidelines both increase the efficacy of lifesaving procedures and decrease the number of medical complications (Treadwell et al. 2014). We posit that the digitization of patient care protocols will reduce disparities that stem from the ascriptive evaluation of patients. Examples of the benefits that stem from the digitization of protocols include: search cost reductions when data integration is standardized (Gefen and Ragowsky 2005), standardized operating procedures (DeSanctis and Poole 1994), and better adherence to best practices (Dexter et al. 2004). We augment this work by showing not just that protocols increase care quality, but that digitized protocols can reduce disparities in care for groups that traditionally receive poorer service, thereby tightening the quality of care gap between social ingroups and social outgroups. Specifically, we ask the following question: What is the effect of clinical decision support systems (CDSS), which provide such protocols, on amputation rates for black and white diabetes patients? This is of concern because, while amputation is often necessary to treat decaying tissue, a wide body of work suggests that amputation rates are notably higher in the black community, while white patients are more likely to have their limbs saved via revascularization procedures (e.g., stents, bypasses; Henry et al. 2011, Regenbogen et al. 2009).

Indeed, significant work attests to the existence of bias in healthcare delivery; inasmuch as black patients are less likely to be selected for transplants, survive cardiac episodes, or receive high-cost lifesaving procedures (e.g., Becker et al. 1993, Jha et al. 2005, Rubineau and Kang 2010). In our focal context, peripheral arterial disease, black patients are more likely have their limbs amputated, while white patients are more likely have their limbs saved through revascularization. This is striking. Revascularization allows the patient to retain mobility and avoid the psychological harm associated with the loss of a limb (Regenbogen et al. 2009). Even more troubling, these differences persist after controlling for sociodemographic factors, comorbidities, and insurance provider (Holman et al. 2011), all of which strongly affect quality of care and course of treatment. Unsurprisingly, the amputation versus revascularization decision is complicated, as physicians need to consider a number of factors: the extent of gangrene, access to follow-up care, general condition of the patient, and life expectancy (Boontje 1979). This complexity, which spans both clinical and social factors, leads to subjectivity in the decision-making process, making it an ideal setting to examine the effect of protocols on decision making. We posit that care protocols facilitated by the CDSS may ameliorate such disparities by ensuring patients receive the right diagnostic tests and consults from revascularization specialists. This context also has notable policy implications, as it is socially undesirable to amputate and permanently impair a patient's ambulatory function when other options are available. Not only is it costly to provide services that facilitate mobility ex post (Houghton et al. 1992), the psychological harm of undergoing a limb amputation is nontrivial (Horgan and MacLachlan 2004).

To determine the size of any such effect, we examine changes in amputation versus revascularization decisions in the wake of hospital adoption of CDSS for black and white diabetes mellitus patients across three states: Florida, California, and Maryland. Data on inpatient visits are drawn from the Healthcare Cost and Utilization Project–State Inpatient Database (HCUP-SID). These data contain the universe of inpatient admissions, as well as ICD-9 diagnoses and procedure codes and socio-demographics of the patient (viz. race). Data on CDSS adoption is drawn from the widely used Healthcare Information and Management Systems Society (HIMSS) Analytics database. Our identification strategy is a difference-in-difference approach, casting adopting hospital-year observations as treatment and hospital-years yet to adopt as control. Identification comes from within hospital changes in amputation rates using hospital fixed effects.

Results indicate that the adoption of CDSS decreases amputation rates for black patients, with no concomitant change in the amputation rates for white patients. This reduction is most pronounced among black patients with the highest ambiguity in their propensity to receive amputations, indicating that decision support systems have the capacity to attenuate bias under uncertainty. Additionally, there is evidence that this observed change is driven by providing the correct tests and consulting the appropriate specialists, rather than changing within-physician decision making, thereby stressing the importance of protocols in the organizational context. Importantly, we see no evidence that these changes in revascularization result in a postponement of eventual amputations, suggesting that the increased revascularization rate is appropriate.

Two contributions stem from this work. First, although significant research has studied the effect of algorithms on racial biases, and the punitive effects they can yield (Angwin et al. 2016, Cowgill 2018, Edelman and Luca 2014, Ge et al. 2016), we demonstrate a means by which information systems can play a beneficial role. Specifically, the ability of CDSS to change organizational protocols, with the objective of adhering to best practice guidelines, can reduce the subjectivity in healthcare delivery. We therefore expand the corpus of approaches that can be used to attenuate unconscious bias. Second, insofar as there can be multiple factors that reduce rates of amputation for black patients, we are able to rule out within-physician change, indicating that the effects are likely driven by adhering to protocols and the proper management of patients by the organization. This underscores the continued need for work that abates individual deleterious behavior, as well as how protocols can ensure equitable opportunities and service to communities at risk.

Clinical Decision Support Systems

A robust body of work attests to the benefits of electronic health record (EHR) systems on the delivery of healthcare (Atasoy et al. 2019). Studies demonstrate that these systems reduce cost, medical errors, adverse drug events, and complications—all while increasing adherence to best practices (Atasoy et al. 2018, Bardhan and Thouin 2013, Chaudhry et al. 2006, McCullough et al. 2010). In this work, we focus on one module of the EHR suite that has been extensively studied, clinical decision support systems (CDSS). These systems work by creating a digital index of patient characteristics, (e.g., diagnoses, test results, age, patient history) that is then compared against a "computerized knowledge base . . . to generate patient specific recommendations" (Garg et al. 2005, p. 1223). During the generation of this digital knowledge base, nurses and physicians are taken through a structured information-gathering process, thereby generating a comprehensive assessment of the patient's condition, rather than a partial picture (which often emerges when processes for information gathering are either ad hoc or not formalized). CDSS are unique in this respect from other EHR systems, which do not impose such information gathering protocols.

In the presence of such protocols, received research indicates that CDSS adoption may reduce bias for at risk patients. Simply, CDSS formalize the management of the patient within the hospital by providing guidance for treatment to the patient care team. This is done in two ways. First, the protocols standardize the suite of diagnostic tests and procedures that patients should receive (Garg et al. 2005). In the case of diabetic patients with peripheral vascular disease, protocols provide the corpus of tests that should be conducted by the physician, such as angiographies and Doppler ultrasounds, to assess the extent of blood flow in major and minor arteries in extremities. These tests give decision makers—viz. physicians—objective information on the severity of the infection and the extent of dead and decaying tissue in the patient's limb, which directly correlates with the need for an amputation. Thus, protocols push decision makers toward a structured information-gathering process to obtain unbiased data on the severity of the patient and reduce the ambiguity in the decision-making process. When asked about the importance of these tests, one physician instrumental in the implementation of protocols in a U.S. academic medical center remarked, "In the case of patients on the margin [between amputation and a limb-preserving procedure], protocols mandate tests that can allow physicians to make an objective call on which procedure should be conducted."

Second, protocols increase the probability that specialists are consulted during the prognostic phase of treatment (Meigs et al. 2003). Specialists can provide a more informed opinion than the marginal practitioner because of their expertise (i.e., training and experience) in a particular field of medicine. In the case of inpatients with peripheral vascular disease, protocols can ensure that the attending physician obtains consults from revascularization specialists. Because of their expertise, such specialists are best suited to provide an informed assessment of whether a revascularization is feasible. Thus, protocols alter the care team that makes the ultimate decision on revascularization by including more knowledgeable practitioners. Interviews with physicians corroborate this intuition. Said one physician, "Think of a diabetic patient who is admitted with a gangrenous foot ulcer. With protocols, the patient will probably be admitted, then the admitting physician will need to wait till the revascularization specialist gives their opinion, and then the decision to amputate will be made." Insofar as these processes allow the patient to be examined by the correct medical staff, who in turn prescribe a more informed treatment plan, it is reasonable that CDSS may decrease bias in amputation decisions. Thus, if the amputation disparity between black and white patients is due to the subjectivity of caregivers, we expect the standardized protocols enabled by CDSS to reduce this racial gap.

Data and Methods

Data

To examine the effect of CDSS in atteuating racial bias in amputation, we combine detailed patient-visit–level data with information on hospital CDSS adoption. Patient-level admissions data are drawn from three states enrolled in the HCUP-SID. Data from Florida and Maryland span 2006–2013. Because of availability, California data range from 2006 to 2010. These states were chosen because of their large and diverse populations and their significant patient heterogeneity (Greenwood et al. 2018). Hospital CDSS adoption comes from the Healthcare Information and Management System Society (HIMSS) database. The sample is started in 2006 because of changes in the HIMSS survey.

Following clinical research convention (Regenbogen et al. 2009), patients in the sample are selected using ICD-9 diagnosis and procedure codes. At least one of the following diagnoses is required for the patient to be included: diabetes with peripheral circulatory disorders (250.7*),[1] lower-extremity arterial atherosclerosis, stenosis, thromboembolism, and/or gangrene (440.2*, 443.81, 443.9, 444.22, 444.81, 447.1*, 785.4). The use of vascular diseases ensures that the physician is choosing to either amputate the patient's limb or conduct a revascularization procedure (e.g., angioplasty, stenting) that can save the limb by improving blood flow to the extremities. Selected patients also must have one of the following procedures: an above/below knee amputation (84.16, 84.17, 84.13, 84.15) or lower-extremity revascularization in the form of bypass, angioplasty, or stent (39.25, 39.29, 39.50, 00.55, 39.90). Patients undergoing both amputation and revascularization during the admission were omitted. Patients coded as neither white nor black were omitted to simplify the comparison across groups. Details on the diagnosis and procedure codes are in Table A1 of the online supplement. Summary statistics are in Table A2 of the online supplement.

Model and Estimation

To estimate the effect of CDSS on racial disparity in amputation, we model the amputation decision for patient i, admitted at hospital j, in year t. Formally,

$$\begin{aligned} Amputation_{ijt} = \beta_0 &+ \beta_1 CDSS_{jt} + \beta_2 Black_i \\ &+ \beta_3 CDSS_{jt} * Black_i + \beta_4 Severity_i \\ &+ \mu_j + \vartheta_t + \varepsilon_{ijt}. \end{aligned} \tag{1}$$

$Amputation_{ijt}$ is zero for any revascularization decision (viz. bypass, angioplasty, stent) and one for amputation. $CDSS_{jt}$ is dichotomous and is equal to one if the hospital has adopted the system at time t, and zero otherwise. $Black_i$ is a binary indicator equal to one if the patient is black, and zero otherwise. Identification of the change in racial disparities after CDSS adoption comes from the interaction of technology adoption ($CDSS_{jt}$) and the patient race indicator ($Black_i$). We include hospital (μ_j) and year (ϑ_t) fixed effects to account for unobserved time-invariant heterogeneity across hospitals, as well as time-specific shocks shared by all hospitals. This is important as unobserved patient severity and care quality may differ across hospitals and revascularization rates may change over time. The identification of the parameter of interest (β_3) in Model (1) is driven by hospitals that adopt CDSS over the duration of our panel. Hospitals that adopt before or after the sample are included to assist with the identification of the other parameters—viz. β_2 and β_4. Note that these hospitals do not assist with the identification of β_3 as they do not experience within-hospital change. Results are robust to the exclusion of hospitals adopting outside the sample from the analysis (Table A10 in the online supplement).

Patient characteristics and risk factors likely correlate with both CDSS adoption and amputation decisions, and thus need to be controlled. First, they may be correlated with the presence of CDSS or patient's race. Second, CDSS adoption may depend on these characteristics. For example, we might expect the hospital to adopt a CDSS if many patients are difficult to diagnose (i.e., are of middling severity) because the CDSS can help with the diagnostic process. On the other hand, we might expect patients to go to CDSS-adopting hospitals, as a sign of the superior ability to diagnose and treat them regardless of race and severity. To account for these, we construct a severity index by predicting the propensity to amputate as a function of observed amputation- and diabetes-related risk factors and their interactions, (e.g., current ICD-9 diagnoses codes, patient age, and gender) using 10% of our sample. This subsample is then excluded when estimating the effect of CDSS on amputation rates. This index, $Severity_i$, measures the conditional average amputation rate for patients with a set of observed risk factors. Details on the construction of this measure are on page A2 of the online supplement. Results are robust to different ways of operationalizing patient severity, such as replacing the single severity metric with ICD-9 diagnoses codes, patient age, and gender in the model (Table A9 in the online supplement). We employ a linear probability model (LPM) for estimation. The LPM has been extensively used to avoid interaction interpretability issues with nonlinear models (Hoetker 2007). Robustness checks using nonlinear estimators—viz. logistic regression and probit—yield similar results (Table A4 in the online supplement). Standard errors are robust and clustered by hospital.

Robustness Tests

Before presenting our results, we first discuss baseline threats to our identification strategy. We examine within-hospital differences in amputation rates across black and white patients after CDSS adoption. Parallel trends in the amputation rates across these patients prior to CDSS adoption is critical for this identification strategy (Angrist and Pischke 2008). Although this assumption is likely to hold during periods of rapid technology adoption (Athey and Stern 2000)—e.g., after the HITECH Act (Atasoy et al. 2019)—it is important to examine preadoption amputation trends to ensure no significant statistical differences. To do so, we modify Equation (1) to include indicators for pre- and post-adoption periods (Autor et al. 2003):

$$Amputation_{ijt} = \beta_0 + \sum_{n=-2}^{2} \alpha_{ni}\beta_n^{'} + \sum_{n=-2}^{2} \alpha_{ni}Black_i\beta_n^{''} + \beta_1 Severity_i + \beta_2 Black_i + \mu_j + \vartheta_t + \epsilon_{ijt}. \quad (2)$$

Intuitively, this model estimates the difference in the amputation rate semiparametrically across black and white patients. α_{ni} is a binary indicator for the time to CDSS adoption in the panel for patient i. If our model is properly identified, then $\{\beta_{-1}^{'}, \beta_{-2}^{'}, \beta_{-1}^{''}\beta_{-2}^{''}\}$should not be significantly different from zero, suggesting no difference across treated and untreated observations for either black or white patients. Further, the effects of CDSS in the years following adoption $\{\beta_1^{''}, \beta_2^{''}\}$ should be negative for black patients. We top- and bottom-code n at 2 and –2, respectively, as most observations are within this range. Results are in Table 2 and Figure 1.

Additional tests to examine threats to validity of results include controlling for hospital-specific time trends, time-varying hospital characteristics, robustness to nonlinear specifications, serial correlation of errors, changes in patient pool over time, and accounting for returning patients. These analyses are in the online supplement (Tables A3–A8). Further, to demonstrate that our results are independent of how severity is modeled, we replicate Model (1) using dummies for the diagnoses codes, age, and gender (in lieu of single severity measure). Results are consistent and in Table A9. Finally, we ensure that results are robust to excluding hospitals that adopt CDSS outside the sample window (Table A10). Results remain consistent.

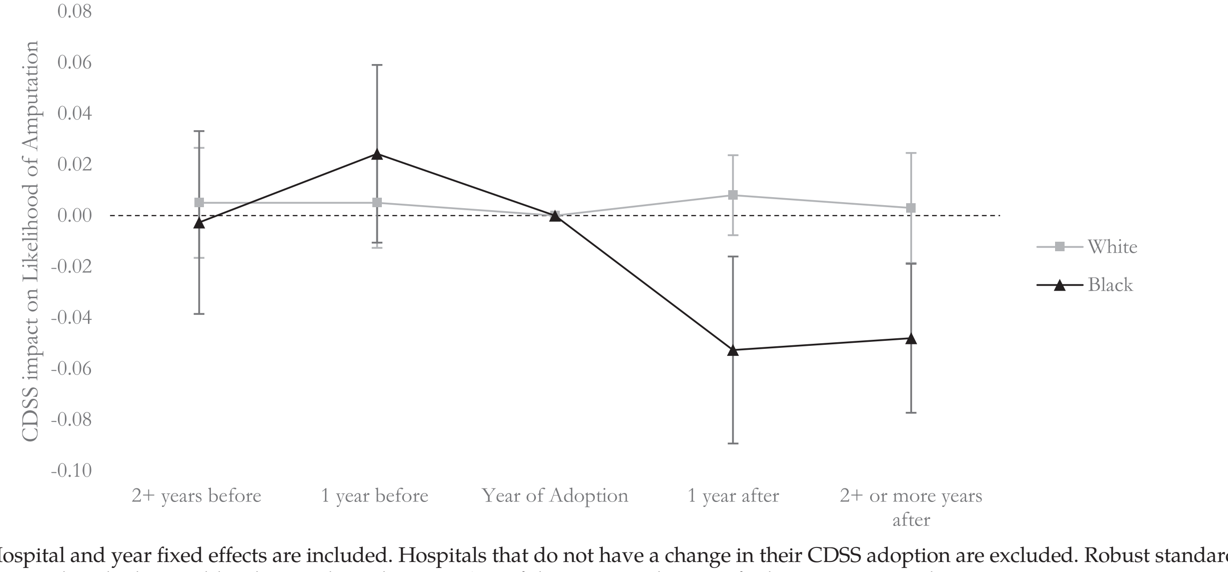
Results

Effect of CDSS on Amputation Decisions

In Table 1, we estimate two models based on Equation (1). We first use the full sample and then restrict the sample to only black patients. In column (1), corroborating prior work, we observe that black patients are significantly more likely to have a limb amputated, *ceteris paribus* (Regenbogen et al. 2009). Further, we see no significant effect of CDSS for white patients, as indicated by *CDSS* coefficient. This parameter is small (–0.001) and precisely estimated (95% CI: –0.013 to 0.011). While we are hesitant to accept the null, this implies that any large amputation reduction in the white population is unlikely. Finally, as indicated by the interaction of *CDSS* and *Black*, there is a large (~4%) and significant reduction in amputation rate for black patients following CDSS adoption. While this does not completely close the gap in amputation rates, it is more than halved. Results from the black patient sample corroborate these findings, again with a 4% drop being observed. Economically, these results suggest that the adoption of CDSS will lead to a reduction of roughly 550 amputations per year among black patients in the United States. Details are on page A3 of the online supplement.

We next assess the validity of the parallel trends assumption (Table 2 and Figure 1).[2] Two important findings are observed. First, there is no evidence of statistical differences across treated and untreated hospitals in the lead-up to adoption. Further, results are consistent with the parallel trends assumption holding for both the black and white populations, suggesting that hospitals about to adopt CDSS are not experiencing heterogeneous racial trends in the amputation/revascularization rate prior to adoption.

Figure 1. Relative Time Model



Notes. Hospital and year fixed effects are included. Hospitals that do not have a change in their CDSS adoption are excluded. Robust standard errors clustered at the hospital level. Error bars depict 95% confidence interval. Year of adoption is omitted.

Table 1. Effect of CDSS on Rates of Amputation DV: Amputation

	(1)	(2)
Variables	All patients	Black patients
CDSS × Black	−0.042***	
	(0.011)	
CDSS	−0.001	−0.040***
	(0.006)	(0.014)
Black	0.083***	
	(0.010)	
Severity	0.900***	0.919***
	(0.011)	(0.014)
Hospital FE	Yes	Yes
Year FE	Yes	Yes
Observations	78,413	18,261
R^2	0.374	0.352

Notes. Hospital and year fixed effects (FE) included. Robust standard errors clustered at the hospital level.
$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.

This supports the intuition that we can treat CDSS adoption as an exogenous event for amputation decisions, conditional upon controls. Second, as expected, there is an immediate and stable decrease in amputation rates post-adoption for black patients, with no concomitant effect for white patients.

Empirical Extensions

Within-Physician Decision Making

Interviews with physicians, as well as a broad survey of prior work, indicates two ways new information can come to the attending physician after the adoption of CDSS: (i) formalized data gathering (including performing diagnostic tests to identify the extent of tissue damage in the limb) and (ii) consultations with revascularization specialists. Either of these approaches would reduce the ambiguity in the decision to revascularize or amputate the limb of the patient. The question then becomes, is the gathered information updating physician behavior because they have more information or is the revelation of information helping the patient be treated by the correct physician?

To explore this question, we replicate our estimations in the presence of physician fixed effects. Intuitively, this approach allows us to test whether there is a significant change in within-physician decision making after CDSS adoption. In other words, by including the physician fixed effect, we can observe whether individual physicians' decisions change, on the margin, after the adoption of CDSS. If the CDSS is giving the focal attending physician better information, and she is able to make a more informed amputation decision, we may see the effect in the presence of a physician fixed effect. We exclude observations where the attending physician has not treated multiple patients (as we cannot observe that same physician over time) and data from California where physician identifiers are not available in HCUP. Results in Table 3 indicate that the inclusion of physician fixed effects renders the effect of CDSS insignificant. Intuitively, this suggests that the effect of CDSS on amputation decisions is driven by shifts to standardized treatment plans and care teams rather than changes in attending physician decision making.

Table 2. Pre- and Post-Adoption Effects DV: Amputation

	(1)
Variables	All patients
CDSS adoption two or more years before	0.005
	(0.011)
CDSS adoption two or more years before × Black	−0.003
	(0.018)
CDSS adoption one year before	0.005
	(0.009)
CDSS adoption one year before × Black	0.024
	(0.018)
Year of CDSS adoption	Omitted
CDSS adoption one year after	0.008
	(0.008)
CDSS adoption one year after × Black	−0.053***
	(0.019)
CDSS adoption two or more years after	0.003
	(0.011)
CDSS adoption two or more years after × Black	−0.048***
	(0.015)
Black	0.078***
	(0.013)
Severity	0.895***
	(0.016)
Hospital FE	Yes
Year FE	Yes
Observations	36,860
R^2	0.370

Notes. Hospital and year fixed effects (FE) included. Hospitals that do not have a change in their CDSS adoption are excluded. Robust standard errors clustered at the hospital level.
$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.

Delayed Amputation

Although results in Table 1 indicate that the adoption of CDSS reduces the likelihood of black patients receiving amputations, it is possible that these revascularization efforts are delaying eventual amputations. This is plausible, as newly vascularized patients may differ in their willingness to adhere to post-surgical care protocols (i.e., follow-up care). If new revascularizations are followed by increased amputation, this would suggest that CDSS leads to unnecessary procedures that place patients at risk and waste resources.

Table 3. Within Physician Changes of Decision Making DV: Amputation

	(1)	(2)
Variables	All patients—with physician FE	Black patients—with physician FE
CDSS × Black	−0.021	
	(0.019)	
CDSS	0.001	0.025
	(0.013)	(0.029)
Black	0.064***	
	(0.018)	
Severity	0.816***	0.856***
	(0.019)	(0.027)
Physician FE	Yes	Yes
Hospital FE	Yes	Yes
Year FE	Yes	Yes
Observations	43,732	9,711
R^2	0.462	0.504

Notes. Hospital, year, and physician fixed effects (FE) included. California data are excluded because of lack of physician IDs. Singleton physicians are excluded due to lack of within physician change. Robust standard errors clustered at the hospital level.
$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.

Therefore, it is important to determine any long-term changes. To test this, we restrict our sample to patients treated in California and Florida.[3] We then estimate the impact of CDSS on receiving a future amputation (at time > t) conditional upon revascularization at time t. We employ the same identification and estimation strategy described for Equation (1). Results in Table 4 indicate that CDSS has no significant effect on long-term propensity to amputate. This provides evidence that CDSS are not merely delaying the amputation decision, but providing a better long-term treatment for patients, thus obviating the argument that increases in revascularization procedures for black patients are inefficient from a resource-allocation perspective.

Table 4. Delayed Amputation DV: Amputation

	(1)	(2)
Variables	All patients	Black patients
CDSS × Black	−0.001	
	(0.006)	
CDSS	−0.001	−0.005
	(0.002)	(0.009)
Black	0.018***	
	(0.006)	
Hospital FE	Yes	Yes
Year FE	Yes	Yes
Observations	43,135	6,698
R^2	0.017	0.030

Notes. Hospital and year fixed effects (FE) included. Results are consistent in the presence of controls for patient severity at time of revascularization. Robust standard errors clustered at the hospital level.
$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.

Heterogeneous Effects by Patient Severity

Our final analysis explores heterogeneous effects across patient severity. In severe cases, amputation might be inevitable and necessary for the patient's health. Alternatively, in minor cases, the decision not to amputate would be self-evident. It is therefore logical to expect the effects of CDSS to be most meaningful in cases of moderate severity, where the decision is unclear and subject to greater discretion.

To examine this, we divide the sample of black patients into quintiles of amputation propensity (i.e., severity) and allow the CDSS effect to vary across propensities. Patients in the lowest quintile are those most likely to receive revascularization procedures based on observed severity, while those in the highest quintile are those most likely to receive amputations. Results indicate that black patients that are most likely to receive revascularization procedures (those in the first and second quintile) and those most likely to receive amputations (those in the fifth quintile) do not experience changes in their amputation rates after the introduction of CDSS. Instead, CDSS lowers amputation rates for black patients in the third and fourth quintiles. These results are compelling as patients in these quintiles cannot be cleanly classified to either receive an amputation or revascularization procedures. Significant physician discretion in the choice of procedure exists for these patients. This suggests that CDSS have an effect for patients for

Table 5. Heterogeneous Effects by Patient Severity DV: Amputation

	(1)
Variables	Black patients
CDSS	–0.006 (0.019)
Second Quintile × *CDSS*	–0.021 (0.020)
Third Quintile × *CDSS*	–0.054** (0.025)
Fourth Quintile × *CDSS*	–0.060** (0.029)
Fifth Quintile × *CDSS*	–0.022 (0.025)
Second Quintile	0.041** (0.020)
Third Quintile	0.135*** (0.024)
Fourth Quintile	0.354*** (0.027)
Fifth Quintile	0.632*** (0.024)
Hospital FE	Yes
Year FE	Yes
Observations	18,261
R^2	0.336

Notes. Hospital and year fixed effects (FE) included. Robust standard errors clustered at the hospital level.
***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

whom there is considerable ambiguity in whether they should receive an amputation or revascularization procedure (Table 5), and provides corroborative evidence that CDSS lead to improved decision making for more uncertain cases.

Concluding Remarks

We investigated whether the imposition of standardized protocols via CDSS in hospitals can reduce amputation rate disparities between black and white patients. An analysis of inpatient data from three states indicates that CDSS adoption cuts the disparity in black versus white amputation rates associated with diabetes mellitus in half, with no significant effect for white patients. In effect, these systems help attenuate the well-known racial disparity in amputation rates. Further, these systems have no significant effect on long-term amputation rates by delaying inevitable treatment. Interviews with physicians at a leading academic health system corroborate our argument that these systems help channel patients to the correct physician, thereby preventing avoidable amputations. Said one physician, "These systems standardize treatment and force patients to have checks with revascularization specialists . . . thus standardizing care across populations."

Our findings inform three streams of research and make critical calls for future work. First, while prior research has studied the effect of digitization on discrimination, we provide evidence that digital protocols can standardize decision making and attenuate racial biases. Prior research has consistently argued that the implementation of digital processes results in standardizing processes and eliminating variance from the organization. However, recent work has indicated the opposite may also occur—i.e., that biases may end up being encoded into digital work. Examples are easy to find: Black Airbnb guests and Uber riders are subject to higher cancellation rates (Edelman and Luca 2014, Ge et al. 2016), judges often dismiss digital recommendations for lighter sentences for minority defendants (Cowgill 2018), and algorithmic policing is more likely to dispatch officers into minority neighborhoods (Angwin et al. 2016). This research indicates that the use of digital protocols and guidelines, rather than a black box approach, offers the opportunity to limit the presence of undesirable biases. This underscores the need for future work on how structured decision making aided by digital systems can reduce bias for complex judgments, notably for decisions that involve significant social interaction and are therefore prone to subjectivity. Further research is needed to explore the boundary conditions of any such effect, when protocols are beneficial, and conditions where they are not.

Second, while prior research has found that CDSS and protocols promote adherence to guidelines of best care, research on the effectiveness of the systems on attenuating disparities in the provision of care is limited. This work demonstrates that benefits from these systems may be heterogeneous. Encouragingly, the benefits accrue to disadvantaged groups in this context. However, it is important to recognize that this may not always be the case. This underscores the need to revisit much of the literature on adherence stemming from protocol adoption to determine for whom protocols have the greatest (least) effects—i.e., which patients and physicians. Finally, prior research has documented the effectiveness of digital protocols on organizational outcomes—e.g., reducing costs and standardization. This work provides evidence that the use of protocols by organizations may reduce disparities in the service they provide by reducing the subjectivity of the service provider. Future work is critical to determine when such changes yield material social gains.

Our findings inform healthcare policy in at least two ways. First, while CDSS adoption and usage rates are near universal in hospitals across the United States because of the HITECH Act of 2010 (Atasoy et al. 2019), it is important that policy makers be made aware of the aftereffects of such interventions (Greenwood et al. 2019). Policy is always in a state of flux, and it is important that framers are informed of the multiple, often unanticipated effects that these may bring. We are able to emphasize an unanticipated benefit of adoption, which lawmakers should make note of as policy continues to be refined. Second, healthcare delivery is rife with multiple persistent biases. Expectant black women and their newborns are more likely to die during childbirth (MacKay et al. 2001, Schoendorf et al. 1992), and women are more likely to die from heart attacks (Greenwood et al. 2018). It is incumbent upon the scholarly community to identify what steps can be taken to ameliorate such biases. In this work, we show the ability of digitized protocols to do exactly that and underscore the need for future research and policy, which can push these benefits further.

This study is not without limitations. First, we are unable to track patients across visits to ambulatory centers, as our data only grant us access to inpatient stays. We cannot thus observe subsequent visits or the progression of treatment and complications in ambulatory settings. Second, our analysis is limited to procedures conducted in three states (Florida, California, and Maryland). Although, these states are large and diverse, future work is needed to determine if these beneficial changes occur across the entire market. Third, while we observe CDSS adoption, we do not observe the adoption of amputation and revascularization guidelines—i.e., we can observe adoption but not use. We thus have error in our treatment measure, suggesting that we may be underestimating the potential effect of CDSS. This may explain the racial gap that persists post-treatment. Fourth, our data do not capture the entirety of the patient care team or its characteristics. This limits our ability to identify the presence of revascularization specialists, residents, nurses, etc., and their contribution to the amputation versus revascularization decision. Further, we are unsure what may drive revascularization specialists to recommend limb-saving procedures. These specialists may better judge the efficacy of the procedure or they may just have an inherent bias toward performing such procedures.

Finally, the period of our analysis saw the two major policy changes: the HITECH Act, which mandated the adoption and use of EHR systems in hospitals across the United States, and the Affordable Care Act (ACA), which expanded health insurance coverage. These policy changes may introduce heterogeneity in our results, although we have taken steps to minimize such concerns. For example, the inclusion of time fixed effects should absorb any changes that affect all observations in a year. Subsample analysis also indicates that results manifest before HITECH comes into effect. It is also worth noting that the insurance-expanding provisions of the ACA only came into effect in 2014 (after the end of our panel), with little notable changes in un-insurance rates before that time (down 10 basis points in our sample and 12 basis points nationwide) (Kaiser Family Foundation 2019). Thus, these policy changes are unlikely to materially affect our findings.

While our findings point to the efficacy of digital protocols in reducing racial disparities when providing care, it is also worth considering if similar measures could be achieved using nondigital or paper protocols. There are at least two ways in which digital protocols differ from paper-based protocols. The first is scope. Digital systems allow hospitals to code a virtually unlimited number of protocols into their systems. In a paper-based environment, there are search and implementation costs to increasing the number of protocols, as doctors then need to spend an increasing amount of time selecting the protocol to implement. The second issue is that of enforceability. Digital protocols allow hospitals to track provider deviations from best practices (e.g., avoiding consults with specialists, performing tests, and restricting medication) (Ransbotham et al. 2016). Digital protocols further allow administrators to identify physicians who disregard guidance from protocols and allow subjectivity to creep into the decision-making process. This increases adherence to guidelines of best care that have been observed after the implementation of digital decision support systems in hospitals (Lobach and Hammond 1997).

Limitations notwithstanding, we are able to demonstrate that digital systems may help overcome systematic differences in healthcare delivery. Standardized decision making in healthcare can ameliorate subjectivity in caregivers' discretionary decisions by ensuring that a full corpus of data are gathered and the right person is treating the patient. While algorithms have gained attention as a means by which bias is often exacerbated, our results indicate that information systems may also alleviate this bias by providing standardized methods to treat everyone equally.

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Endnotes

[1] ICD codes have a hierarchical structure. * depicts all ICD codes that fall under a given code.

[2] Note that these estimations exclude all hospitals adopting outside the sample to ensure the relative time dummies are correct.

[3] Maryland is omitted because of a coding change that prevents us from reliably tracing patients over time.

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