Clinical Decision Support Randomized Controlled Trial

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**Introduction**

This document provides an overview of the Public Use Data files associated with analyses of a randomized controlled trial studying the effect of clinical decision support (CDS) on scan orders by providers at a health system. A detailed codebook and replication code for portions of Doyle et al. (2019) is available at [Harvard Dataverse](https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/BRKDVQ). Users should consult these guides when using the data.

**Contents**

Project Description

Public Use Data Files Description

References and Replication Code

Citation or Public Use Data

**Project Description**

In 2014, the Centers for Medicare and Medicaid Services (CMS) announced an impending mandate that in order to be reimbursed, high-cost scans must be ordered using an approved clinical decision support (CDS) system. CDS is a software that consults clinical guidelines to deliver assessments of procedure appropriateness to providers at the time of order entry. While several observational studies have been conducted to assess the impact of CDS, there had been no large-scale randomized controlled trials. We partnered with a health system to conduct a randomized controlled trial studying the effect of CDS on scan ordering. The CDS system employed by the health system, ACR Select, was designed by the National Decision Support Company. ACR Select provides appropriateness scores to scan orders paired with clinical indications, along with patient age and gender, using a ruleset created by the American College of Radiology. The CDS at the health system was configured to trigger a best practices alert (BPA) if a scan order received an appropriateness score of 1-6 and there was an alternative scan with a higher score that could be ordered instead.

In November 2016, health care providers (‘providers’) at the health system were emailed with the opportunity to opt-out of the study. There were 13 providers who decided to opt-out, and 3,511 were randomized into treatment and control groups. The study period began on December 15, 2016 and lasted for one year. The CDS RCT analyzed scan order outcomes across the treatment and control groups and conducted robustness checks. The health system provided data on scan orders and completions, patient encounters and patient demographics, provider employment and demographics, and health care encounters when the BPA was shown (or ‘fired’). The National Decision Support Company provided data on appropriateness scores, alternative scans, and the version of the ACR ruleset used within health system’s CDS.

**Public Use Data Files Description**

**1. Provider, Randomization, Controls and Outcomes Data (prov\_all\_stats\_sp.dta and prov\_all\_stats\_qp.dta)**

These datasets contain scan order outcomes, provider descriptive information, and variables generated for robustness checks in addition to variables generated for internal analyses. All tables in Doyle et al. 2019 can be reproduced using this dataset and the replication code except for Tables S3 and S4. Analysis for those tables is based on scan-level data, which we are not able to release publicly. For all other analysis, the unit of observation is the unique encrypted **provider\_key**. Only treatment and control providers are included; they are distinguished with the variables **treated** and **control**. Therefore, the variables **eligible** and **consent** are all 1; **opt\_out** is all 0. For detailed descriptions of the health system context, randomization, provider workflow, descriptions of variables and discussion, please see the main text and supplementary appendix of Doyle et al. 2019. Definitions of specific variables are in the codebook.

In prov\_all\_stats\_sp.dta, variables that end in “\_q” are used for demographic or lagged ‘quiet period’ controls. During the quiet period (which lasted 8 months before the RCT began), imaging orders and alternatives were scored, but the BPA was not shown. Missing demographic information is replaced by -9999 (except within **provider\_age**) within the control variables, and a separate variable is generated to indicate missing values of the main variable. The following sections describe the demographic, scan, and encounter variables within prov\_all\_stats\_sp; the descriptions are the same for quiet period variables in prov\_all\_stats\_qp.dta. Note that prov\_all\_stats\_qp.dta does not contain any study period variable values, and so the quiet period variables do not end in “\_q”. Missing demographic information is not replaced by -9999 in prov\_all\_stats\_qp.dta because the demographic information is used for summary statistics and not control variables.

If a provider did not have any encounters or scans within the study or quiet period, the scan or encounter outcome is 0. Because we do not know the exact point in the study in which providers left the health system, providers who left are still included in most analyses. As a robustness check, we exclude providers who left during the study period.

**a. Provider variables**

Descriptive variables on provider demographics, background and employment status were generated for use as OLS regression controls, robustness checks and heterogeneity analyses. The variable **quit\_qtr** contains the quiet or study period quarter in which a provider left the health system; it is zeroed at the start of the study period. Indicators **Iquit\_*Q*** flag the period or quarter in which the provider quit, where ***Q***is quiet (qp), study (sp), or quarters 1-4 (qtr1, qtr2, qtr3, qtr4).

We constructed indicators **most\_enc\_*L*\_q** to flag the most common location of in-person encounters for the provider in the quiet period, where ***L*** is emergency department (ed), hospital non-ED (ip\_non\_ed), or outpatient setting (op).

The variable **provider\_age** contains the age of the provider at the start of the study period. Age is missing for one provider, which is flagged by **provider\_age\_miss\_q**. We constructed indicators for 5-year age bins starting at 23 and ending at 67, **prov\_age\_*B*\_q**, where ***B*** is the age range (inclusive) covered by the bin. A final bin covers providers aged 68-85. Providers with an age below the median are flagged with the indicator **prov\_age\_med\_below**. Conversely, provider with an age equal to or above the median are flagged with the indicator **prov\_age\_med\_eq\_above**.

One of the eligibility requirements for study participation was that providers must possess an MD, DO, DPM, NP, PA, or CNM degree. The degree type, ***D***, of the provider is indicated by **provider\_degree\_*D*\_q.**  **provider\_degree\_oth\_q** indicates providers that have either a DPM or CNM degree. Provider specialty is indicated by **provider\_specialty\_*S*\_q**, where ***S*** is assistant, general medicine, nurse, specialist or student (resident). The variable **provider\_graduation\_q** contains the years from the provider’s graduation until 2016, while the indicator **provider\_graduation\_miss\_q** flags providers missing year of graduation. Likewise, the indicator **provider\_male\_q** distinguishes male providers; **provider\_male\_miss\_q** flags providers missing sex information. There are no providers missing sex information.

Provider demographic and background data were obtained from the health system in a dataset unique by encrypted provider ID. The indicators for primary quiet period encounter location were calculated from a dataset containing patient encounters from that period, unique by encounter key.

**b. Scan orders**

The variables **scan\_*T*** contains the number of scans per type ***T*** that the provider ordered in the study period; **scan\_*T*\_q** contains the number ordered by the provider in the quiet period. ***T*** represents the following scan types: high-cost (hc), low-cost (lowcost), magnetic resonance imaging (MRI, mr), computed tomography (CT, ct), positron emission tomography (PET, pet), nuclear medicine (NM, nm), either PET or NM (pet\_nm), x-ray (xr), mammogram (mm), ultrasound (us), fluoroscopy (fl), bone densitometry (bd), and other (other). High-cost scans are defined to include only CT, MRI, PET, and NM. Low-cost scans consist of x-rays, mammograms, ultrasounds, fluoroscopies, and bone densitometry. “Other” scans are neither high- nor low-cost.

The variable **scan** contains the total number of high-cost, low-cost and other scans ordered in the study period, while **scan\_performed** contains the total number of performed scans. **scan\_q** and **scan\_performed\_q** are the quiet period equivalents.

**scan\_*S*\_cl** contain the number of scans of type ***S*** ordered in the study period that were canceled; **scan\_*S*\_cl\_q** are the quiet period equivalents. ***S*** includes CT (ct), MRI (mr), and PET or NM (pet\_nm). The variables **scan\_*SQ*** report the number of scans of type ***S*** ordered within quarter ***Q***; **scan\_*S*\_cl*Q*** report the number of scans of type ***S*** ordered within quarter ***Q*** that were canceled. ***Q*** are quarters 1, 2, 3, and 4 of the study period.

**scan\_hc\_annualized** is only found in prov\_all\_stats\_qp.dta, which lasted less than a year. It annualizes the quiet period count of high-cost scans ordered by the provider.

Data on scan orders and performance were obtained from health system in a dataset unique by order ID and clinical indication ID.

**c. Scan appropriateness**

The variables **scan\_hc\_scored\_*R*** contain the number of high-cost scan orders that CDS gave appropriateness scores in the ranges, ***R***, of 1-3, 4-6, 7-9 and 1-9, inclusive. **scan\_hc\_scored\_ *R*\_ct** is the number of CT scans with appropriateness scores in the ranges R; **scan\_hc\_scored\_ *R*\_mr** is the equivalent for MRI. **scan\_hc\_scored\_*R\_*q**, **scan\_hc\_scored\_ *R*\_ct\_q**, **scan\_hc\_scored\_ *R*\_mr\_q** are the quiet period equivalents. The variables **scan\_hc\_scored\_*RQ***, **scan\_hc\_scored\_*R*\_ct*Q***, and **scan\_hc\_scored\_*R*\_mr*Q*** report the number of high-cost scans, CT scans, and MRI with appropriateness scores in the ranges ***R*** that were ordered in quarter ***Q***, where ***Q*** are quarters 1, 2, 3, and 4 of the study period.

"Targeted scans" are high-cost scans that would have triggered the BPA during the entire study period if ordered by a treatment user provider. These scans have an appropriateness score of less than 7 and for the same clinical indication, there is a higher-scoring alternative scan. The variable **scan\_bpa\_new** contains the number of targeted scans the provider ordered in the study period. **scan\_bpa\_new\_1\_3** and **scan\_bpa\_new\_4\_6** contain the total number of targeted scans with scores 1-3 and 4-6 that the provider ordered in the study period. **scan\_bpa\_new\_ct** and **scan\_bpa\_new\_mr** present the total number of targeted CT scans and targeted MRI that the provider ordered in the study period. **scan\_bpa\_old** is the number of targeted scans ordered by the provider in the study period under the BPA logic in place for the first four months of the trial. Under this logic, scans would have triggered the BPA if scored 1-6 or a strictly-higher scoring alternative was available. The variable **scan\_bpa\_shut\_off** contains the number of scans ordered by the provider during the study period that would trigger the BPA under the logic in place for the first four months of the trial but not subsequent months. These scans are either scored 1-6 without a strictly higher-scoring alternative or are scored 7-9 with a strictly higher-scoring alternative. **scan\_bpa\_shut\_off\_q** is the quiet-period equivalent. **scan\_bpa\_new\_q**, **scan\_bpa\_new\_1\_3\_q**, **scan\_bpa\_new\_4\_6\_q**, **scan\_bpa\_new\_ct\_q**, **scan\_bpa\_new\_mr\_q**, **scan\_bpa\_old\_q**, and **scan\_bpa\_shut\_of\_q** are the quiet period equivalents. The variables **scan\_bpa\_new*Q***, **scan\_bpa\_new\_1\_3*Q***, **scan\_bpa\_new\_4\_6*Q***, **scan\_bpa\_new\_ct*Q***, and **scan\_bpa\_new\_mr*Q*** report the number of targeted high-cost scans, targeted high-cost scans scored 1-3, targeted high-cost scans scored 4-6, targeted CT scans and targeted MRI that were ordered in quarter ***Q***, where ***Q*** are quarters 1, 2, 3, and 4 of the study period. **scan\_bpa\_old*Q*** reports the number of targeted high-cost scans ordered in quarter ***Q*** under the BPA logic in place for the first four months of the trial.

The number of targeted scans ordered by a provider in the study period that were performed at the health system is stored in **scan\_bpa\_new\_performed**, the quiet period equivalent is **scan\_bpa\_performed\_q**. We analyze targeted scan orders by location with the variables **scan\_order\_enc\_loc\_*N*** in the study period and **scan\_order\_enc\_loc\_*N*\_q** in the quiet period, where ***N*** is emergency department (ed), hospital non-ED (ip\_non\_ed), outpatient setting (op), or not in-person (oth).

**scan\_bpa\_eligible\_annualized** is only found in prov\_all\_stats\_qp.dta, which lasted less than a year. It annualizes the quiet period count of targeted scans ordered by the provider.

Data on scan orders and performance was obtained from the health system in a dataset unique by order ID and clinical indication ID. Appropriateness scores and scan alternatives were obtained from NDSC in a dataset unique by decision support session ID, procedure ID and indication ID, and the study team averaged these encounter-level variables by provider to reach a provider-level dataset. Scan order locations were obtained from the health system in a dataset of encounters unique by encounter key.

**d. Unscored scans**

The number of high-cost scans that could be given an appropriateness score are stored in **scan\_scored\_cds** for study period orders, **scan\_scored\_cds\_q** for quiet period orders. Some scans did not receive an appropriateness score directly from CDS and would not cause the BPA to fire; we were able to use the ruleset to determine appropriateness of these scans. The number of high-cost scans with an appropriateness score assigned with the ruleset instead of directly from CDS are stored in **scan\_scored\_imp** for the study period and **scan\_scored\_imp\_q** for the quiet period. High-cost scans for which an appropriateness score was not assigned by CDS and could not be assigned using the ruleset are counted in **scan\_unscored\_all** and **scan\_unscored\_all\_q** for the study and quiet periods, respective. We refer to these scans as “unscored”. Unscored CT scans and MRI ordered in the study period are stored in **scan\_unscored\_all\_ct** and **scan\_unscored\_all\_mr**; the quiet period analogs are presented in **scan\_unscored\_all\_ct\_q** and **scan\_unscored\_all\_mr\_q**.

We analyze the sources of unscored scans in **scan\_unscored\_*U*** and **scan\_unscored\_*U*\_q** in the quiet and study periods, respectively. ***U*** are the causes of unscored scans, labeled by handoff\_worker, custom\_ind,

nonc, onc, rlst, fltr, medi, smartset, sys, external, and other. ***U* = handoff\_worker** describes scans that were unscored because the orders were placed by clerical workers or technician on behalf of providers in the study. Clerical workers and technicians are not required to submit structured indications (symptoms), and CDS requires structured indications in order to assign appropriateness scores. Similarly, scan orders at health system that were faxed in from external facilities are not required to be paired with structured indications and thus are frequently unscored. These unscored scans are described in ***U* = external**. ***U* = custom\_ind** describes unscored scans that were paired with clinical indications that are custom to health system. While appropriateness scores are provided for most scans paired with health system custom indications, CDS does not provide appropriateness scores for some pairings of scans and health system custom indications. Likewise, for some scans and indications, the American College of Radiology (ACR) does not provide appropriateness scores for patients of certain age ranges or genders; the omission of scoring is called “age-gendering filtering”, and counts of affected scans are provided in ***U* = fltr**. There are also clinical indications that ACR has chosen not to score regardless of patient age and gender; most are within oncology. Unscored scans with these oncology indications are described by ***U* = onc**, while counts of scans ACR has chosen not to score with non-oncology indications are provided in ***U* = nonc**. Some types of high-cost scans are ordered at the health system that are not included in the ACR ruleset and therefore cannot be scored. These scans are described by ***U* = rlst**. Over the course of the study, some new procedures became available at the health system and were not included in the version of the ACR ruleset the health system used throughout the study; these unscored scans are described by ***U* = sys**. There were four high cost scan types that could be scored by the ACR ruleset (Medicalis scans), but for most of the study, the health system subjected the orders to a separate best practices alert and turned off the BPA studied by this evaluation. Since they do not receive an appropriateness score, they are described by ***U* = medi**. Before May 4th 2017, structured indications were not required for scans ordered within “SmartSets”, which are bundles of procedures ordered for specific diagnoses. Unscored scans ordered within Smartsets are distinguished by ***U* = smartset**. Other sources of unscored scans are combined in ***U* = other**.

**f. Robustness Checks**

Variables were generated to study methods of avoiding the best practice alert that may be attempted by treated providers. For instance, treated providers may ask control providers or non-randomized individuals to place the order on their behalf, as they are not subject to CDS. We refer to the passing of orders in a way that avoids CDS as “strategic hand offs”. The number of high-cost scans with a treated ordering provider and non-treated individuals placing the order are counted in **handoff\_strategic\_all**. Strategic hand-offs to control providers and non-randomized individuals, such as nurses, providers new to health system and those who opted out, are stored in **handoff\_strategic\_con** and **handoff\_strategic\_not\_rand**, respectively. The quiet period analogs are **handoff\_strategic\_all\_q**, **handoff\_strategic\_con\_q**, and **handoff\_strategic\_not\_rand\_q**.

To avoid CDS, it is possible that providers may reduce their number of patient encounters entirely. Or, CDS could create a large time and hassle cost as to significantly reduce the number of in-person patient encounters that treated providers can complete. The total number of in-person patient encounters that providers are associated with are stored in **encounter** and **encounter\_q** for the quiet and study periods. We also provide the number of encounters by in-person location with the variables **encounter\_*N*** in the study period and **encounter\_*N*** **\_q** in the quiet period, where ***N*** is emergency department (ed), hospital non-ED (ip\_non\_ed), or outpatient setting (op).

**g. Patient demographics**

Since these variables are not used as regression controls, they are only found in prov\_all\_stats\_qp.dta. **pat\_table\_age** provides the average age of patients with in-person encounters associated with that provider. **pat\_table\_male** and **pat\_table\_white** describes the share male patients and white patients associated with that provider’s in-person encounters, respectively.

**2. Provider, Randomization, Controls and Outcomes Data (prov\_all\_stats\_sp.dta and prov\_all\_stats\_qp.dta)**

This dataset contains counts and shares of scored high-cost scans ordered in the study period with the top 30 most common clinical indications paired with scored high-cost scans ordered in the quiet period. The dataset is unique by **provider\_key**. Only treatment and control providers are included; they are distinguished with the variables **treated** and **control**. **consent** is all 1. Counts are stored in **ind\_*M*** and shares are stored in **sh\_ind\_*M***, where ***M*** is an abbreviation of the clinical indication. **ind\_other** and **sh\_ind\_other** contain the counts and shares of scored high-cost scans ordered per provider paired with clinical indications that were not among the 30 most common quiet period indications. sh\_ind\_M and share\_ind\_other are missing if the provider did not order any scored high-cost scans in the study period. **total\_ind** contains the total number of scored high-cost scans ordered per provider. The shares of scored high-cost scans ordered in the study period with the top 30 most common clinical indications paired with scored high-cost scans ordered in the quiet period were used for an F-test of change in distribution of indications between treatment and control providers.

**References and Replication Code**

Code has been made available that replicates the analyses in Doyle et al. (2019) which are performed on the publicly available data. The code includes a Stata .do file (cds\_replication.do) which calls on several subprograms. A list of the replicated analyses along with instructions for running the .do file can be found at the top of this master .do file.

**Citation for Public Use Data**

Doyle, Joseph; Abraham, Sarah; Feeney, Laura; Reimer, Sarah; Finkelstein, Amy, 2019, "Clinical decision support for high-cost imaging: a randomized clinical trial", https://doi.org/10.7910/DVN/BRKDVQ, Harvard DataVerse, V1