

# The Unintended Consequences of Medicare's Wage Index Adjustment on Device-Intensive Hospital Procedures

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Since the mid-1980s, hospital reimbursement for acute care inpatient stays for Medicare beneficiaries has been based on a payment structure known as the Inpatient Prospective Payment System (IPPS). The vast majority of acute care hospitals in the United States serve Medicare beneficiaries and receive IPPS payment rates. Further, Medicare's IPPS rates are a common benchmark used by other payers to set their own payment rates. The IPPS categorizes inpatient cases into Medicare Severity–Diagnosis Related Groups (MS-DRGs) based on their clinical similarity and case complexity. The patient's principal diagnosis and up to 24 secondary diagnoses, including any comorbidities or complications, determine the MS-DRG assignment of each case. Other factors influencing DRG assignment include a patient's gender, age, and discharge status disposition.<sup>1</sup> Using Medicare beneficiary claims data from prior years, CMS calculates a relative weight for each MS-DRG based on resources used to treat Medicare beneficiaries in those groups. To determine the payment amount for each case, CMS multiplies a standardized base payment amount across all cases at all hospitals (\$5961 in 2021) by the hospital's area wage index, which reflects the expected differences in local market prices for labor and labor-related costs. To determine the wage index for each core-based statistical area (CBSA) and statewide rural area, CMS compares the mean hourly wage for employees of hospitals in that area with the nationwide mean, after controlling for differences in hospitals' occupational mix, and then applies certain adjustments. After the base payment amount has been adjusted by the wage index, this amount is multiplied by MS-DRG payment weight of the case and also several other policy adjustments, such as adjustments for transfers to other hospitals, high-cost outlier cases, hospitals conducting medical education, and hospitals serving a relatively high share of Medicaid and low-income patients. Put differently, there are additional adjustments to payment beyond the wage index adjustment.

Although adjustments on various sources of variation are common, a source of variation that has not been taken into account under the current payment adjustment scheme is variation in production technology across alternative clinical interventions. These interventions involve a different mix of labor and device inputs,

## ABSTRACT

**OBJECTIVES:** To study the association between Medicare's wage index adjustment and the differential use of labor-intensive surgical procedures and medical device-intensive minimally invasive clinical procedures across the United States.

**STUDY DESIGN:** We combine a conceptual model and an empirical investigation of its predictions, applied to aortic valve replacement, to study the relationship between variation in Medicare wage index payment adjustment across hospital referral regions (HRRs) and the utilization of transcatheter aortic valve replacement (TAVR) and surgical aortic valve replacement (SAVR) in these areas.

**METHODS:** Using detailed individual Medicare claims data for 2013–2018 and a novel geographical crosswalk to nest information on Medicare's wage index and utilization of TAVR and SAVR, we estimate a mixed effects Poisson regression model across HRRs to test our hypotheses.

**RESULTS:** We find regional variation in Medicare wage index adjustment levels to be correlated with differential TAVR and SAVR utilization and growth over time. In particular, in HRRs where the wage index is half the national mean there is a 35% decline in the rate of TAVR use and in HRRs where the wage index is 50% higher than the national mean there is a 52% increase in the rate of TAVR use.

**CONCLUSIONS:** Consistent with our framework and hypothesis, our results highlight the importance of adjusting Medicare hospital inpatient payments for device-intensive procedures. Absent such adjustment, access to appropriate interventions may be reduced in areas with low wage index, and lower reimbursement, when driven by wage index adjustment, may influence the treatment approach selected.

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and the overemphasis placed on labor inputs through the wage index adjustment is likely to affect the choice of clinical intervention. The heterogeneity in treatment of aortic stenosis is an example of this type of variation. Aortic stenosis occurs when the heart's aortic valve narrows, affecting normal blood flow. In terms of treatment choice, many patients are candidates for both surgical aortic valve replacement (SAVR), a traditional open surgery procedure, as well as transcatheter aortic valve replacement

(TAVR), a newer minimally invasive procedure. In 2015, CMS added separate MS-DRG codes for TAVR with and without complications. According to CMS IPPS final rule, SAVR reimbursement was higher than that for TAVR, with the gap in reimbursement increasing over the years. Mean reimbursement for TAVR across all DRGs fell from \$52,998 in 2017 to \$50,732 in 2018 to \$49,113 in 2019, whereas mean reimbursement for SAVR across all DRGs rose from \$54,035 in 2017 to \$56,039 in 2018 to \$58,863 in 2019 (FY 2013-FY 2019 MEDPAR, CMS IPPS Final Rule).

Compared with SAVR, TAVR is associated with equivalent or improved morbidity and mortality across all levels of surgical risk.<sup>2-8</sup> Because TAVR is less invasive than SAVR, patient recovery is often faster with shorter lengths of stay.<sup>9</sup> TAVR patients have reported improved short-term quality of life and lower total health resource utilization compared with patients undergoing SAVR. From an economic standpoint, minimally invasive procedures are less labor intensive (during the index procedure) but more device intensive than traditional open-heart surgeries. The less invasive approach requires less labor; however, the technology and device costs are higher.

Medicare's current IPPS methodology includes a potential bias against procedures requiring the use of implantable devices, which account for a large share of the overall cost of the procedure. As mentioned previously, CMS adjusts hospital payment based on facility-specific factors such as the size of the hospital's medical resident training program, the number of low-income hospital patients treated, and, most important to this analysis, the hospital's wage index. The bias against implantable device procedures lies in the fact that hospitals' costs for implantable devices do not vary substantially by geography, but Medicare's payments to hospitals for these procedures are adjusted by their geographic location through the wage index adjustment. For procedures like TAVR, for which implant device costs account for more than 50% of total procedure costs, Medicare payments to hospitals in areas with a high wage index tend to be adequate, whereas in areas with a low wage index, the wage index adjustment can reduce payments to levels that are less than the device cost. This bias creates asymmetry in financial incentives for hospitals in choosing between clinical interventions.

The results from our conceptual model and our empirical investigation of AVR suggest that there are potential unintended consequences when no payment adjustments are made for differences

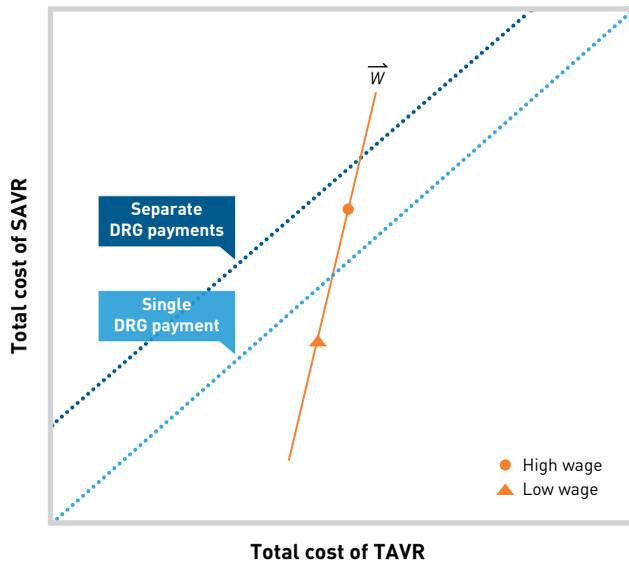
## TAKEAWAY POINTS

- ▶ An unintended consequence of Medicare's wage index adjustment policy is that it incentivizes labor-intensive surgical procedures over medical device-intensive minimally invasive clinical procedures in areas with lower labor costs.
- ▶ We demonstrate this both conceptually and empirically by studying aortic valve replacement.
- ▶ We find that hospital referral regions with a wage index half the national mean have 35% fewer device-intensive procedures and hospital referral regions where the wage index is 50% higher than the national mean have a 52% higher rate of these procedures.
- ▶ Adjustments on a single input (labor) have the potential to distort the choice of clinical interventions.

in production technology (ie, labor-intensive vs device-intensive inpatient procedures). For illustrative purposes, we define device-intensive procedures as those for which the majority of the index hospitalization costs are attributable to the implantable device. The main consequence is hindering the adoption of device-intensive interventions in general, with current wage index adjustment practices, which overemphasize labor costs relative to device costs, exacerbating this issue. As mentioned earlier, one of the factors that adjusts a hospital's overall payment under IPPS is the Medicare wage index, which adjusts hospital payments to reflect area differences in the cost of labor. This adjustment results in the reallocation of payments to reflect differences in the relative cost of labor across inpatient facilities in different areas while maintaining budget neutrality. However, this principle is violated when reimbursing for device-intensive procedures. Areas with low wage index adjustment are receiving reimbursements that cannot cover the cost of devices while supporting labor-intensive procedures, given the low cost of labor. The goal of maintaining a consistent payment structure across IPPS hospitals, while recognizing that the cost of labor varies in markets across the nation, may create a financial distortion affecting the desirability of and patient access to new, device-intensive clinical procedures.

CMS, through its wage index adjustment, further compensates hospitals based on differences in labor costs across the United States. This penalizes areas with a low wage index twice. First, the adjustment lowers the overall reimbursement, often leading to financial losses when incorporating the cost of device. For example, in some areas of the South, payment rates can be lower than the cost of the valve itself. Second, the savings from shifting to less labor-intensive procedures are very small in areas where labor is relatively cheap and are eliminated under a separate DRG payment that matches payment to lower labor intensity, while ignoring the fact that these savings are the result of using a device-intensive intervention. The focus on labor cost adjustment, not accounting for cost differences in technology and/or devices, may lead to a distortion in the sensible and just original adjustment behind the wage index—maintaining a consistent payment structure across IPPS hospitals.

In the next section we provide a simple conceptual framework to derive empirical hypotheses, which we test in the subsequent sections. Our results suggest that the current reimbursement practice may create scenarios in some parts of the country in which

**FIGURE 1.** Choice Between TAVR and SAVR as a Function of Wage Index Adjustment

DRG, diagnosis-related group; SAVR, surgical aortic valve replacement; TAVR, transcatheter aortic valve replacement.

TAVR payment rates, profitability, and contribution margins affect TAVR treatment patterns, penetration, and patient access to care.

### Procedure Choice: A Conceptual Framework

In this section, we provide a simple model of procedure choice and wage adjustment to derive the hypotheses for our empirical analysis. The full details of the derivations are in [eAppendix A](#) (eAppendices available at [ajmc.com](#)).

We model SAVR as a labor-intensive procedure and TAVR as a device-intensive procedure. In addition, we characterize the hospital's production to be a fixed-proportions function, using Leontief production technology, in which each AVR requires exactly 1 unit of device and a different number of labor units depending on the technology used. The total costs of AVR are derived by combining the level of inputs needed with the corresponding input prices. Because the number of labor units used in TAVR is smaller while the price of the valve is higher, the difference in total costs of TAVR and SAVR is a function of the wage rate.

We start with a scenario in which CMS payment for AVRs is identical and calculated such that hospitals break even on SAVR cases, with relative high-wage areas receiving higher reimbursement per AVR compared with low-wage areas. In this case, SAVRs always yield zero economic profits and TAVRs can be either profitable or unprofitable depending on the area wage rate. More specifically, we show that under this scenario the hospital adopts TAVR if and only if the area wage is higher than the ratio of the difference in device costs and the difference in labor intensity.

Our second scenario relates to changes in reimbursement rates, separating CMS payments for TAVR and SAVR. Because the number of labor units used in TAVR is smaller, CMS pays less for TAVR. We model the difference in profitability between the 2 procedures and show that TAVR is even more affected by wage index adjustment.

**Figure 1** demonstrates the results of our model. The axes represent the total cost of SAVR (y-axis) and total cost of TAVR (x-axis) for different levels of wage, holding labor intensity and device prices constant. The light blue dotted 45-degree line represents the collection of points for which hospitals are indifferent between SAVR and TAVR under the first scenario (ie, a single AVR payment for SAVR and TAVR), whereas the dark blue dotted line represents the collection of points for which hospitals are indifferent between SAVR and TAVR under the second scenario (ie, a higher AVR payment for SAVR compared with TAVR, due to lower labor intensity of TAVR procedures). The solid orange line represents a vector of wages, holding labor intensity and device prices constant. Wages increase along this line, such that the orange triangle represents a lower wage compared with the orange circle.

Under the second scenario, both wages (high and low wages) are below the dark blue dotted line suggesting that TAVR is less profitable, and therefore hospitals in these areas will not select TAVR from a pure profit perspective. Under the first scenario, hospitals in high-wage areas will prefer TAVR whereas hospitals in low-wage areas will prefer SAVR.

Moreover, raising the cost of the TAVR device will shift the wage vector down and to the right, making it less likely that hospitals will adopt TAVR for any level of area wages. Therefore, a key hypothesis of our model is that hospitals in areas with higher wage index adjustment are more likely to utilize TAVR and that this utilization is more pronounced compared with SAVR. Next, we will empirically test this hypothesis.

## STUDY DESIGN AND METHODS

Our empirical analysis evaluates the effect of wage index on the use of TAVR and SAVR in each hospital market over time. We use individual-level Medicare beneficiary data from CMS to construct variables for TAVR and SAVR utilization over time and across markets. Our data span the years 2013 to 2018.

To better align our work with the literature on geographical variation in care patterns, we target hospital labor market areas and we construct wage indexes for hospital referral regions (HRRs), units of geographic measure pioneered by researchers at Dartmouth University.<sup>10</sup> HRRs were designed specifically to measure variations in health care across the United States. They are defined by assigning hospital service areas to a region where the greatest proportion of major cardiovascular procedures are performed. Thus, instead of using other geographic definitions, the benefit of HRRs is that they provide a more natural representation of the hospital market. Nevertheless, the Medicare wage index is calculated at the CBSA level. There is no crosswalk between CBSAs and HRRs, as the

former are a collection of counties whereas the latter often cross county and state lines.

To assign a Medicare wage index for each HRR, we create a novel crosswalk between CBSAs, the geographical area at which the wage index is determined, and HRRs, the geographical area used for studying hospital utilization. In essence, we break CBSAs into their corresponding zip codes and use these zip codes to reconstruct all 306 HRRs. We provide a brief description of the creation of the analysis data and crosswalk below. A more detailed technical description can be found in [eAppendix B](#).

First, we use the CMS Standard Analytical File 100% Fee-for-Service (FFS) database from 2013 to 2018. The CMS FFS payer database includes information on the health care services that are covered for beneficiaries enrolled in Medicare Part A and Part B. Medicare beneficiaries’ data are used to link the utilization of individual beneficiaries over time and across providers.

Next, we link each Medicare FFS beneficiary with an AVR claim to an operating physician. Using the National Provider Identifier, a unique 10-digit identification number issued to health care providers in the United States by CMS, we are able to link each AVR with the zip code for its operating provider. Using our zip code–level procedural data, we roll the data up to the HRR level, providing us with an HRR-level count of annual TAVR and SAVR claims.

It is important to note that although the wage index is determined at the CBSA level, hospitals may receive special adjustments to their wage index, leading to potential variation across hospitals within CBSAs. Using an analysis of detailed hospital-level wage index data for 2015 and 2016, we conclude that the variation in wage index within CBSA is negligible in comparison with the variation in wage index across 407 CBSAs (F-value of 234.43).

A generalized linear mixed effects Poisson regression model was used to evaluate the association between wage index and growth of TAVR use across HRRs between 2013 and 2018,

$$\log Y_{ij} = n_{is} = \beta_0 + \beta_j T_{ij} + \alpha W_i + b_{oi} + b_{ij} T_{ij} + \log HRR_i,$$

where the outcome is the logarithm of the expected number of TAVR procedures  $Y_{ij}$  for the  $i$ th HRR ( $i = 1, \dots, 306$ ) at the  $j$ th year. The parameters  $\beta_j$  are the fixed effects for year,  $T_{ij}$ , with 2013 as the reference year, and the parameter  $\alpha$  is the fixed effect of wage index,  $W$  (per unit increase). The parameters  $b_{oi}$  and  $b_{ij}$  are the random intercept and slopes, respectively, for the  $i$ th HRR. The HRR population size for 2016 is included in the model as an offset. The above model assumes that  $Y_{ij} | b_{oi}, b_{ij} \sim \text{Poisson}(\lambda_{ij})$ ; and  $b_{oi}, b_{ij} \sim \text{iid } N(0, G)$  where  $G = \sigma^2 \rho^{|i^* - j^*|}$  is a first-order autoregressive covariance structure. The standard errors are clustered at the HRR level to account for within-HRR correlations over time. The Poisson model assumes the conditional mean count is equal to the conditional variance. We assessed this assumption by calculating the ratio of the  $\chi^2$  statistic to its corresponding degrees of freedom for both SAVR and TAVR. Both ratios were below 1.2, which is identified as the threshold in the literature.<sup>11</sup>

**TABLE.** Prevalence of Performed TAVRs Across the 306 HRRs

Analysis variable: rate of TAVR per 100,000			
Year	HRRs	Mean	SD
2013	306	2.3071838	3.4247296
2014	306	3.6229368	4.7514526
2015	306	5.3063800	5.5322237
2016	306	7.7634476	7.3495404
2017	306	10.2666742	9.0538149
2018	306	11.3489140	9.4154950

HRR, hospital referral region; TAVR, transcatheter aortic valve replacement.

We fit 2 mixed effects Poisson models: model 1, which is fit to evaluate the effect of wage index on the (logarithm of the) expected number of TAVRs (ie, the rate of use of TAVR procedures for each HRR over the years 2013–2018), and model 2, which is fit to evaluate the effect of wage index on the rate of use of SAVRs for each HRR over the years 2013 to 2018.

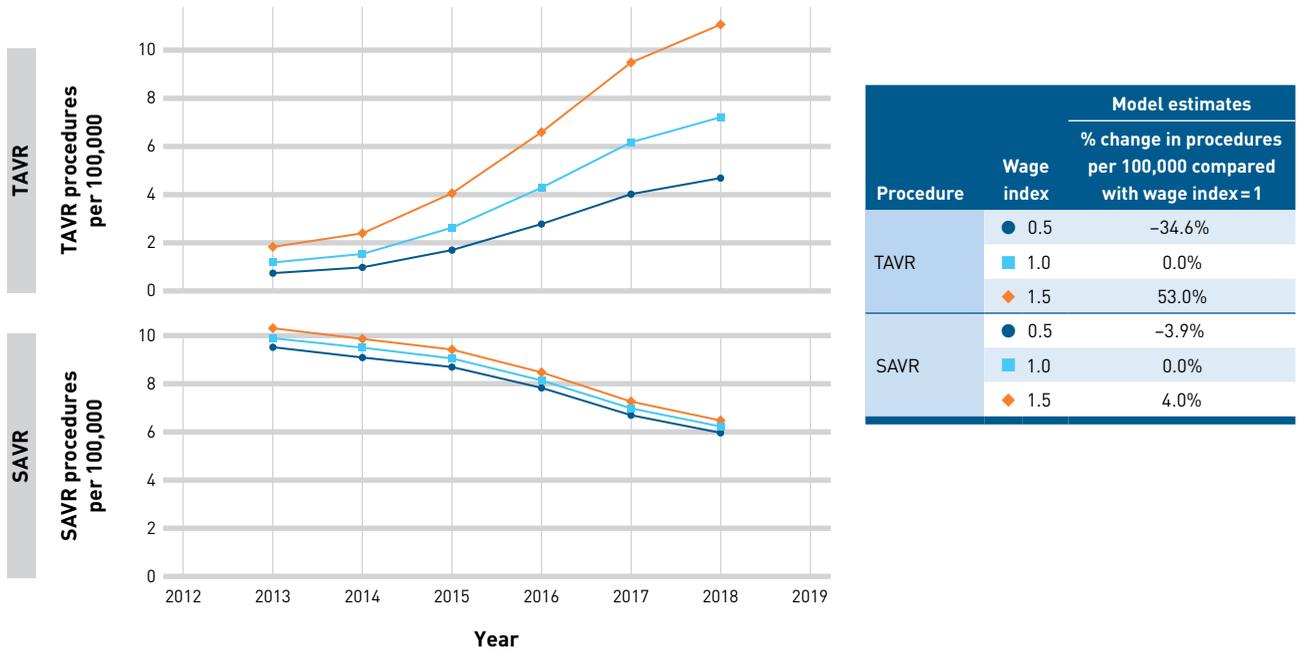
Using the mixed effects Poisson model, we predict the rate of use in TAVR (and SAVR) procedures over time across HRR and evaluate any significant deviations in growth from the national mean. In our conceptual framework above, we hypothesized that geographical variation in wage index adjustment across HRRs would have little or no effect on SAVR utilization and growth. The mixed effect Poisson models were fit using the GLIMMIX procedure in SAS version 9.4 (SAS Institute).

## RESULTS

Our study population includes 330,663 Medicare patients who received an AVR in 1 of 306 HRRs across the United States between 2013 and 2018. The **Table** depicts the prevalence of performed TAVRs per 100,000 individuals across different HRRs. It shows that the prevalence in the United States has increased from an average of approximately 2 TAVRs per 100,000 individuals in 2013 to more than 11 TAVRs per 100,000 in 2018. Note that these effects are true across the entire distribution, with the SD increasing over time. This suggests that the geographical variation in the prevalence of TAVRs has increased over time as well.

The results from fitting the Poisson models are provided in **Figure 2**. For model 1, all the parameter estimates are statistically significant and positive, suggesting that there is a significant rate of growth in TAVR use over time and also that the rate of growth in TAVR use is more pronounced in HRRs with higher wage index (Table). For example, when the wage index is 0.5 (half the national mean) there is a 35% decline in the rate of TAVRs; conversely, when the wage index is 1.5 (50% higher than the national mean), there is a 52% increase in the growth of TAVRs. For model 2, the opposite is observed. The rate of SAVR significantly declined over time, independent of wage index. In fact, from model 2 the effect of wage index is not statistically significant ( $\beta_0 = 0.080$ ;  $P = .6984$ ).

**FIGURE 2.** Regression Results for TAVR vs SAVR Penetration, by Wage Index\*



	Model fixed effects results					
	Model 1: TAVR			Model 2: SAVR		
Intercept	-12.160	0.367	<0.0001	9.299	0.203	<0.0001
[reference: 2013]						
Year 2014	0.257	0.037	<0.0001	-0.044	0.020	0.0283
Year 2015	0.778	0.059	<0.0001	-0.090	0.019	<0.0001
Year 2016	1.258	0.055	<0.0001	-0.193	0.017	<0.0001
Year 2017	1.622	0.048	<0.0001	-0.348	0.015	<0.0001
Year 2018	1.775	0.039	<0.0001	-0.462	0.013	<0.0001
Wage index (per unit increase)	0.850	0.370	0.0222	0.080	0.205	0.6984

SAVR, surgical aortic valve replacement; TAVR, transcatheter aortic valve replacement.

\*Note that the wage index has a statistically significant effect on the growth of TAVR but no effect on SAVR. An increase in the wage index predicts an increase in TAVR use. For example, when the wage index is 0.5 (half the national mean) there is a 35% decline in the rate of TAVRs; conversely, when the wage index is 1.5 (50% higher than the national mean) there is a 52% increase in the growth of TAVRs.

Overdispersion ratios for model 1 and model 2 are 1.11 and 1.15, respectively, which suggest no problems concerning overdispersion.

For robustness, we modeled the probability of TAVR vs SAVR (ie, TAVR share) using a generalized mixed effects logit. A scatter plot of the probability of TAVR against TAVR use per 100,000 HRR population is provided in Figure 3. The solid line in Figure 3 is a locally weighted scatter plot smoother. The results of the model fit are provided in a table under the figure. Also included in this table are the results of the generalized linear mixed effects Poisson model. Both models give similar results. This is not surprising because the

probability of TAVR (there are only 2 options) is highly correlated with TAVR use. From the model, we can see that there is a 2-fold increase in the odds of TAVR relative to SAVR per unit increase in wage index. Likewise, there is a 2-fold increase in the relative rate of TAVR per unit increase in wage index. Modeling both outcomes gives similar results.

Put together, our results suggest that geographical variation in the use of TAVR is highly sensitive to Medicare’s wage index payment adjustment levels in these regions, whereas SAVR procedures, while reducing in prevalence, are less sensitive to wage index adjustments.

## DISCUSSION

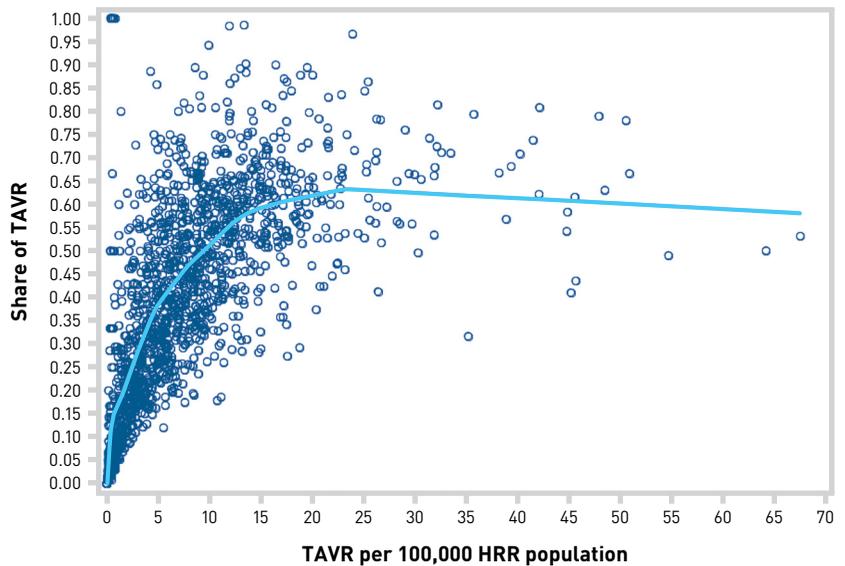
The current IPPS does not capture differences in choice of clinical technology: labor-intensive open surgery vs device-intensive minimally invasive procedures. In this paper, we estimated the relationship between the magnitude of the wage index adjustment and prevalence of utilization of different clinical technologies. An adjustment originally designed to level the playing field is causing potential distortion in hospital choices. Lacking an adjustment for heterogeneity in cost of delivering different interventions may distort the adoption and utilization of new clinical, high-value procedures, such as TAVR.

Using a simple model of procedure choice and wage index adjustment, we derived the hypotheses for our empirical analysis. The key prediction of our economic model was that hospitals in areas with lower labor costs (and hence, lower wage index adjustments) adopt innovative technologies such as TAVR at a slower rate than regions with higher labor costs (ie, high wage index adjustments).

Using detailed individual Medicare claims data from 2013 to 2018, we created a novel crosswalk between the geographical area at which the wage index is determined, the CBSA, and HRRs. We then tested the hypotheses above by estimating a mixed effects Poisson regression model across HRRs, geographic areas that have been extensively used in health services research because of their accuracy in describing patterns of hospital use for patients living within the region as well as their success in capturing regional variation in utilization and cost.

We found a high degree of regional variation in the use of TAVR and SAVR across HRRs. Our empirical results suggested that this variation is driven, at least partly, by variation in wage index adjustment across regions. The determinants of regional variation in health care utilization and spending are not well understood,<sup>12,13</sup> but some explanations for this variation include factors such as underlying health status, as well as supply-side access to care,<sup>14</sup> market concentration,<sup>15</sup> socio-economic factors,<sup>16</sup> patient preferences,<sup>16</sup> physician preferences,<sup>17,18</sup> and physician practice styles.<sup>19</sup> In line with the hypothesis provided by our conceptual framework, we also found that the wage index has a statistically significant effect on the growth of TAVR but no effect on SAVR.

**FIGURE 3.** A Scatter Plot of the Probability of TAVR Against TAVR Use per 100,000 HRR Population



Generalized linear mixed effects logit and Poisson models								
Effect	Logit model Odds of TAVR relative to SAVR (share of TAVR)				Poisson model TAVR usage per HRR population			
	Log OR	SE	P	OR (95% CI)	Log RR	SE	P	RR (95% CI)
2014 vs 2013	0.4617	0.0155	<.0001	1.587 (1.539-1.636)	0.2569	0.0635	<.0001	1.293 (1.142-1.464)
2015 vs 2013	0.844	0.0149	<.0001	2.326 (2.259-2.259)	0.7778	0.0592	<.0001	2.177 (1.938-2.444)
2016 vs 2013	1.2966	0.0145	<.0001	3.657 (3.555-3.762)	1.2582	0.0545	<.0001	3.519 (3.163-3.916)
2017 vs 2013	1.6696	0.0144	<.0001	5.310 (5.162-5.462)	1.6216	0.0482	<.0001	5.062 (4.605-5.563)
2018 vs 2013	1.8655	0.0146	<.0001	6.459 (6.277-6.646)	1.775	0.0386	<.0001	5.900 (5.470-6.364)
Wage index (per unit increase)	0.6743	0.2893	.0205	1.963 (1.113-3.460)	0.8501	0.3698	.0222	2.340 (1.133-4.830)

HRR, hospital referral region; OR, odds ratio; RR, relative rate; SAVR, surgical aortic valve replacement; TAVR, transcatheter aortic valve replacement.

### Limitations

This paper looks at a regulatory dimension and finds an association between Medicare payment adjustment, which varies regionally, and variation in utilization of various clinical interventions. Future studies could assess the relative importance of payment adjustment policies in explaining regional variation in health care utilization.

Moreover, our analysis applies our conceptual framework to a single procedural application. Further research is needed to test the generalizability of our predictions to other clinical domains, involving a choice between labor-intensive open surgery procedures and device-intensive minimally invasive interventions.

## CONCLUSIONS

The logical and just concept behind the wage index payment adjustment—maintaining a consistent payment structure across hospitals—holds when there is a single clinical intervention to consider. Nevertheless, when new clinical treatments can improve patient health and well-being by reducing health risks and shortening recovery time, the focus on labor cost adjustment, not accounting for the underlying production of clinical interventions, has the potential to lead to a distortion in access to such new clinical treatments.

As medical technology continues to improve and innovate, more procedures will become device intensive and provide better overall value to patients, but if the reimbursement structure continues to penalize these types of procedures in certain geographic regions, the value that they provide will go unrecognized and overall system spend will not be optimized. Moreover, areas with high labor costs tend to be more affluent, potentially creating an unintended disparity in access to advanced medical technology along sociodemographic lines. ■

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**Authorship Information:** Concept and design (GD, CG, SC, GG, KM, WI); acquisition of data (CG, MR, SC, GG, KM); analysis and interpretation of data (GD, CG, LL, MR, SC, GG, KM, WI); drafting of the manuscript (GD, CG, LL, SC, GG, KM, WI); critical revision of the manuscript for important intellectual content (GD, CG, LL, SC, GG, KM, WI); statistical analysis (GD, CG, MR, GG, WI); obtaining funding (SC, KM); administrative, technical, or logistic support (SC, KM); supervision (GD, SC, KM); and conceptual framework, including modeling, analysis, interpretation, and writing (LL).

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## eAppendix A

Assume the following Leontief production technology, where each aortic valve replacement (AVR) requires exactly one unit of device ( $D$ ) and  $\alpha^i$  units of labor ( $L$ ). The number of AVRs performed is given by:

$$Q^i = \min \left\{ \frac{L}{\alpha^i}, D \right\},$$

where  $i = \{S, T\}$ ,  $S$  for SAVR and  $T$  for TAVR. Because SAVR is a labor-intensive procedure than TAVR  $\alpha^S - \alpha^T > 0$ ,  $L \geq 0$ ,  $D \geq 0$ .

Total costs ( $TC$ ) of AVR are given by:

$$TC^i = wL + r^i D,$$

where  $w$  is the wage rate (labor cost) and  $r^i$  is the cost of the device.

### Scenario 1: Single payment for SAVR and TAVR (baseline case)

Our baseline case uses a single DRG payment ignoring the actual surgical technology used. More specifically, we assume that wage index adjustments are set such as using SAVR yields zero economic profit regardless of the geographic location of the hospital. Then the equilibrium levels of labor ( $L^*$ ) and device ( $D^*$ ) are

$$L^* = \frac{\partial TC^S}{\partial w} = \alpha^S Q^S \quad \text{and} \quad D^* = \frac{\partial TS^S}{\partial r^S} = Q^S.$$

CMS will ensure budget neutrality by setting  $\pi^S = 0$ . From this condition, the unit payment for SAVR is

$$p^S(w; \alpha^S, r^S) = \alpha^S w + r^S \quad (0.1)$$

Equation (1.1) shows that the payment for SAVR, given by  $P^S$ , is a function of labor cost,  $w$  and parameters  $(\alpha^S, r^S)$ . The payment is increasing in the labor cost or the cost of the device

Next we assume that CMS adjusts payments for TAVR using the production weights for SAVR, such that the profitability of TAVR is given by:

$$\pi^T(w) = p^S(w; \alpha^S, r^S) Q^T - w \alpha^T Q^T - r^T Q^T. \quad (0.2)$$

Substituting  $p^S$  which is given by (1.1) gives

$$\pi^T(w; \alpha^S, \alpha^T, r^S, r^T) = Q^T [w(\alpha^S - \alpha^T) + (r^S - r^T)]. \quad (0.3)$$

Equation (1.3) shows that  $\pi^T(w) \geq 0$  if and only if  $w(\alpha^S - \alpha^T) \geq (r^T - r^S)$ .

Equation (1.3) also shows that profit for a hospital using TAVR is a function of the wage index.

Because  $\frac{\partial \pi^T}{\partial w} > 0$ ,  $\frac{\partial \pi^T}{\partial(\alpha^S - \alpha^T)} > 0$ ,  $\frac{\partial \pi^T}{\partial(r^T - r^S)} < 0$ , the relative labor and device intensities, such that, higher wage, larger differences in labor intensity and lower cost of device favors the adoption /use of TAVR/

Because  $\pi^S(w) = 0$  by construction, the hospital adopts TAVR if  $\pi^T(w) \geq 0$  and SAVR if  $\pi^T(w) \leq 0$ . Thus, the hospital adopts TAVR if and only if

$$\hat{w}(\alpha^S, \alpha^T, r^S, r^T) > \frac{r^T - r^S}{\alpha^S - \alpha^T}, \quad (0.4)$$

where  $\hat{w}$  is the cutoff value of wage for the adopting TAVR.

## Scenario 2: Separate payments for SAVR and TAVR (based solely on labor adjustment)

Next, we consider the post-2015 case of instituting separate DRG payments for SAVR and TAVR. Since these payments continue to adjust payment largely based on labor inputs, it created imperfect price adjustment for TAVR procedures. In particular, assume that the price for SAVR deviates from the price for TAVR by  $\delta > 0$ . Hence  $p^T(w) = p^S(w) - \delta$ . As a result, SAVR will be profitable even when the total cost of TAVR is higher than the total cost of SAVR.

Under imperfect payment adjustment, the profits for TAVR are,

$$\pi^T(w; \alpha^S, \alpha^T, r^S, r^T, \delta) = Q^T [w(\alpha^S - \alpha^T) + (r^S - r^T) - \delta]$$

Now,  $\pi^T(w) \geq 0$  if and only if  $w(\alpha^S - \alpha^T) \geq (r^S - r^T) + \delta$ .

Thus, the hospital adopts TAVR if and only if

$$\tilde{w}(\alpha^S, \alpha^T, r^S, r^T) \geq \frac{r^T - r^S}{\alpha^S - \alpha^T} + \frac{\delta}{\alpha^S - \alpha^T}. \quad (0.5)$$

Because  $\hat{w} < \tilde{w}$ , having an imperfect (in this case undercompensating) price adjustment for TAVR, means an even higher wage index is needed for TAVR adoption to take place. If the price adjustment would instead accounted for the differential cost of device, wage index adjustment would not have adversely affected TAVR adoption.

## eAppendix B

### Variations in Care – TAVR SAVR Medicare Geographic Data crosswalk to HRR and Wage Index

The CMS FFS Payer database lists provider information including provider number, street address, city state and zip code. Using the zip code data and the Hospital Referral Region Zip Code Crosswalk, the provider is grouped into the proper HRR. The CMS wage index file provides the wage index by Core Based Statistical Areas and also provides geographic information of CMS Hospitals in a given CBSA. Zip code data for the CMS hospitals are matched to the provider zip codes which allows a wage index to be assigned to the provider. From these relationships, the wage index within the HRR is determined by the average of the provider wage indices within the HRR.

Note that the CMS wage index files are for hospitals whereas the CMS FFS Payer data set is at the physician or similar level so there is not always a matching zip or CBSA. Therefore, there are zip codes within an HRR that have no wage index associated with them. CMS also maps a lot of providers into rural areas or state with no CBSA overlaps. In addition, multiple CBSA's can be contained within an HRR and therefore multiple wage index values which is why the mean wage index is used and does result in wage index variation within the HRR and can be worthy of additional study.

- Sources
- TAVR SAVR Patients – CMS FFS Payer Database
- HRR Zip Codes Crosswalk – Dartmouth 2016 Zip Code to HSA to HRR
- CMS FY 2016 Wage Index File

### Process Diagram

