The Correlation Between Patient Comorbidities and Bundled Payment Expenditures

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The Correlation Between Patient Comorbidities and Bundled Payment Expenditures

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Abstract

TITLE: The Correlation Between Patient Comorbidities and Bundled Payment Expenditures

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Purpose: Episode-based payments have been developed as an alternative payment methodology to reduce unnecessary healthcare spending and improve outcomes for acute episodes of care. In this study we examine eleven different acute episodes of care to determine the correlation between a patient's comorbidity burden and their total medical expenditures for a longitudinal 90-day episode-of-care.

Methods: Using historical claims data, patients admitted for one of the defined episodes of care were assigned a clinical risk score using the Elixhauser Van-Walraven Comorbidity Index (EVCI). Total medical expenses were summed over a longitudinal 90-day episode of care using the Medicare grouping methodology. A correlation analysis was used to assess the association between patient EVCI score and longitudinal 90-day medical expenditures.

Results: The correlation between EVCI and episode expenditures ranged from the highest correlation for major bowel surgery ($R=0.22$; $p < 0.0001$) to the lowest correlation value for double joint replacement lower extremity ($R= -0.05$; $p = 0.62$). The results also showed variability in the range of EVCI scores for different conditions. Congestive heart failure (EVCI: 23.19; SD 12.25) had the highest average EVCI score indicating a high-degree of comorbidity amongst patients. Whereas cervical spinal fusion surgery (EVCI: 7.38; SD 11.12) had the lowest average EVCI score.

Conclusions: The correlation between patient EVCI score and longitudinal 90-day expenditures varied across different acute episodes of care, but were found to demonstrate an overall weak correlation**.**

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Glossary:

ACO	Accountable Care Organization
APM	Alternative Payment Model
BPCI	Bundled Payment for Care Improvement
CABG	Coronary Artery Bypass Graft Surgery
CHF	Congestive Heart Failure
CMS	Centers for Medicare and Medicaid Studies
EDW	Enterprise Data Warehouse
EVCI	Elixhauser-Van Walraven Comorbiditiy Index
HCC	Hierarchical Condition Categories
ICD-10-CM	International Classification of Disease, 10th edition, Clinical Modifications
LOESS	Locally Weighted Scatter Plot Smoothing
MS-DRG	Medicare Severity Diagnosis Related Group
SD	Standard deviation
STS-PROM	Society of Thoracic Surgeons Predicted Risk of Mortality
TME	Total Medical Expenditures

Introduction

The fee-for-service reimbursement model has been noted for its inability to reduce costs or incentivize care coordination among healthcare providers.[1] The Centers for Medicare and Medicaid Services (CMS) have begun advancing efforts to enhance the value of care through alternative payment models (APM) whereby health care providers are financially accountable for both the cost and quality of the care they deliver to patients.[2] One new model of health care payment involves the bundling of payments for an acute episode of care in order to reduce unnecessary spending and improve the coordination of care delivery between health care providers both during and after the hospitalization.[1,2] By accepting an episode-based bundled payment in lieu of traditional fee-for-service payments, health care provider organizations are incentivized to reduce health care spending, based on a historical spending target, while maintaining certain quality measures. If the 90-day healthcare expenses for a patient fall below the spending target, providers are able to retain the additional savings as a bonus, however if healthcare spending is greater than the target providers are not reimbursed for the additional spending.[3] CMS launched the first bundled payment program - the Bundled Payment for Care Improvement (BPCI) program - in 2013 and followed that with additional bundled payment programs focused on cardiac, orthopedic, and oncology episodes of care.[3] A number of commercial insurers have similarly developed bundled payment models for acute episodes of care. Despite some uncertainty regarding the long-term prospect of the CMS bundled payment programs,[4] early results in the field of joint replacement have shown 90-day bundled payments to yield significant health care savings.[5,6] Yet the success of bundled payments rely on provider reimbursements being tied closely to the costs of patient care.[7] Large variation in patient health

care expenditures presents a difficult challenge for hospitals and health care providers as they seek to limit spending above set spending targets, or risk financial losses.[7-9]

To better prospectively identify patients with high anticipated health care expenditures, patient comorbidities have been highlighted as an important variable in understanding heterogeneity in patient populations.[10,11] Patient comorbidities refer to the simultaneous presence of multiple acute and chronic conditions in addition to the principal diagnosis. Twenty-one percent of Americans are defined as having comorbidities, with the burden of comorbidities increasing with age.[12] Patients with a higher comorbidity burden are thought to be more medically complex, at risk of developing adverse outcomes (complication, readmission, etc.) and more likely to require additional services resulting in a more expensive episode of care.[12] Whereas patients with fewer comorbidities are thought to be more healthy and require less services resulting in lower health care expenditures. Given that most health care providers do not preferentially select patients for treatment based on their comorbidity burden, understanding a patient's comorbidities may provide insight into the patient's anticipated healthcare expenditures and help physicians target care management resources and additional support services, to avoid adverse outcomes and mitigate financial losses within a bundled payment. Risk prediction tools, such as the Elixhauser-Van Walraven Comorbidity Index (EVCI) are commonly used by researchers to quantify the comorbidity burden of a patient by assigning a weighted score to patients based on 30 acute and chronic diagnoses obtained within their discharge records.[13,14] Prior research has shown there to be a limited association between comorbidity indices and health care expenditures.[15,16] Yet to date, few studies have assessed the relationship between a patient's comorbidity burden, as measured by the EVCI, and their associated longitudinal 90-day episode spending.

In this study, we look to understand how variation in longitudinal 90-day episode spending is explained by a patient's EVCI score. Using administrative claims data from one health system we evaluate this relationship across eleven different acute episodes-of-care, without controlling for additional factors. In this study, we hope to identify whether the use of a comorbidity index may provide value in anticipating the expenditures of diverse patients and could be useful for health care providers and hospital administrators looking to analyze population health data. As more physicians and hospitals transition to episode-based payments and other risk-based payment models there will be a need for enhanced analytics to provide insight into the variation in health care expenditures.

Student Role

This study was developed following a summer management internship at the Partners Healthcare Center for Population Health, where the student author was involved in soliciting feedback from physicians and health care administrators about how the health system would track and measure financial performance in bundled payments. During this project, it was noted that additional patient risk-stratification tools would be helpful in predicting bundled payment expenditures for a given patient. Based on these observations, the author worked with physician administrators at the Center for Population Health to develop this study looking at the association between a patient's comorbidity index and their expenditures across a longitudinal 90-day episode of care. The author was involved in the design of the study as well as the review of literature regarding comorbidity indices, risk-adjustment, and bundled payments. The student was involved in the analysis of the data with statistical support from a staff statistician at the Center for Population

Health, Anamika Chauduri, PhD. Interpretation of the data and drafting of the manuscript was conducted by the student. The software required to calculate patient EVCI risk scores existed within the Partners Enterprise Data Warehouse system prior to the design of this study.

Methods

Patient Cohort

We conducted a retrospective cohort analysis using administrative claims data from Partners Healthcare, an academic integrated health system in Eastern Massachusetts. Eligible patients were fee-for-service Medicare beneficiaries and commercially-insured beneficiaries, managed through the Partners Healthcare Accountable Care Organization (ACO) and hospitalized at an affiliated acute-care hospital for a principal diagnosis between January 1, 2012 and December 31, 2015. Eleven different episodes of care were included in the study based on their Medicare Severity-Diagnosis Related Group (MS-DRG) including: Major Bowel Surgery (MS-DRG: 329-331), Coronary Artery Bypass Graft Surgery (CABG) (MS-DRG:231-236), Cardiac Valve Surgery (MS-DRG:216-221;266-267), Cervical Spinal Fusion (MS-DRG: 471-473), Fractures Femur and Hip/Pelvis (MS-DRG:533-536), Congestive Heart Failure (MS-DRG:291-293), Major Joint Replacement of Lower Extremity (MS-DRG:469-470), Major Joint Replacement of Upper Extremity (MS-DRG:483), Spinal Fusion Non-Cervical (DRG:459-460), Double Joint Replacement Lower Extremity (MS-DRG:461-462), and Stroke (MS-DRG:61-66). The eleven different episodes were selected to cover a range of medical and surgical acute episodes of care. The data included in the study was de-identified and did not include descriptive characteristics for patients.

Comorbidity Index

Patients in the study were assigned a clinical risk score using the Elixhauser-Van Walraven Comorbidity Index (EVCI) based on historical administrative data.[13] The EVCI is a weighted point system that uses 30 different acute and chronic diagnoses identified within a patient's discharge records to summarize a patient's disease burden and their predicted risk of mortality within the hospital (See Appendix Table 1a).[13] The EVCI summarizes a patient's diagnoses into a single numeric score using diagnosis codes identified using the *International Classification Disease, Ninth Edition, Clinical Modifications* (ICD-9-CM). EVCI scores were calculated for patients using published algorithms[17]. The EVCI was developed by van Walraven et al.[13] as a modification of the existing Elixhauser comorbidity score originally published by Elixhauser et al.[18] The van Walraven modification used the 30 binary diagnoses included in the original Elixhauser methodology to create a summary index value which decreased the risk of over-fitting or model convergence in statistical modeling.[13] Of note, EVCI scores can either be a positive or negative value. Compared to other comorbidity risk indices, the EVCI has demonstrated superior ability to predict mortality in hospitalized patients and is widely used as an indicator of patient comorbidity burden.[14,19] While other risk indices such as the CMS-Hierarchical Condition Categories (CMS-HCC) have been shown to be effective in predicting risk in the Medicare population,[20] our patient cohort was composed of both Medicare and commercially-insured patients.

Ninety-Day Bundled Payments

Total medical expenditures (TME) for each episode of care were summed over a 90-day period to create a longitudinal episode expenditure value. The starting date for each episode was the

date of the initial hospital admission, with the end of the episode occurring 90-days following the index admission date. The 90-day bundled payment was developed to match the Model 2 episode definitions created for the BPCI program.[21] Model 2 combines spending for acute hospital care as well as post-acute care, including all related Medicare Part A and Part B services throughout the duration of the episode. This includes all inpatient, outpatient, readmissions, post-acute care, and durable medical equipment. Claims inclusion and exclusion criteria were similar to criteria developed by Medicare.[21] The methodology used for calculating 90-day bundled payment amounts incorporated Episode Grouper software employed by Medicare in the development of BPCI.[22] The Episode Grouper technology identifies the start of the episode based on a trigger event code during the initial hospitalization and chronologically examines claims to assign additional relevant codes to the disease episode.

Episodes with expenditures falling two standard deviations above and below the mean for each episode were excluded from the analysis consistent with Medicare protocols for outlier episodes.[21] Various time lengths have been proposed for bundled payment programs (thirty-day, sixty-day, etc.)[9], the ninety-day period was selected based on its use in many of the early bundled payment programs designed by CMS and other payer entities.[21] The MS-DRG is a prospective payment rate established to reduce variability in Medicare hospital reimbursements. The payment amount for the MS-DRG is based on a basic unit amount that can be adjusted depending in part on a patient's inpatient complications and comorbidities.[23] In this study, multiple categories of MS-DRG's were included for each episode to incorporate a diverse cohort of patients with comorbidities and complications. While comorbidities are included in the MS-DRG determination, which accounts for inpatient spending, the MS-DRG does not account for

variation in healthcare spending during the post-discharge settings of care which is taken into account in this study's longitudinal 90-day measure of spending.

Statistical Analysis

To assess the strength of the association between patient EVCI score and 90-day episode expenditures, we used the Pearson correlation coefficient analysis. Significance for the correlation coefficient was calculated at $P < 0.05$. Descriptive statistics (mean, standard deviation, min, max) were calculated for each episode. The eleven different episodes of care were tested independently. The statistical approach employed in this study was limited by the data fields available for study as is noted in the limitations. We used nonparametric locally weighted scatter plot smoothing (LOESS) to characterize the relationship between EVCI and 90-day episode expenditure to better understand the underlying trends in the data.[24] We report both the correlation coefficients and the significance of the correlation for each episode.

Using a two-tailed t-test for a difference between two independent means and the assumptions of a null mean of no difference between groups, a standard deviation for each episode based on initial descriptive statistics, and an alpha of 0.05, our study was adequately powered at 100% to determine a significant difference of 0.1%, for each episode that were tested. All analyses were conducted using SAS version 9.3 (SAS Institute; Cary, North Carolina).

Results

Our study sample included n=13,916 total independent patient episodes from January 1, 2012 to December 31, 2015. There was variability observed in the number of patients within each

episode depending on the stochastic nature of patient presentations during the study period. Total number of episodes ranged from n=7,264 for major joint replacement lower extremity to n=102 for double joint replacement lower extremity (Table 1). Patient demographics were not available within the dataset.

The average EVCI score across the different episodes varied by more than two-fold (Table 1). Acute episodes where patients presented with the highest mean EVCI comorbidity score included congestive heart failure with an average EVCI of 23.19 and a standard deviation of 12.25 and cardiac valve surgery with an EVCI of 18.16 and a standard deviation of 11.21. Whereas episodes with the lowest mean EVCI scores included major joint replacement lower extremity with an EVCI of 7.55 and a standard deviation of 9.67 and cervical spinal fusion with an EVCI of 7.38 and a standard deviation of 11.12.

Across all episode groups there was significant variation in 90-day episode expenditures both between episodes and within episodes (Table 1). The average 90-day bundled payment expenditure amount ranged from $22,317 for an episode of congestive heart failure, to $77,936 for a cardiac valve surgery episode. Large standard deviations in episode expenditures were also observed within episode groups (Table 1).

Weak correlation was observed between EVCI comorbidity score and 90-day episode expenditures with some variability between different episodes (Table 2). Episodes with the highest level of correlation included major bowel surgery ($R = 0.22$; $p < 0.0001$), stroke ($R = 0.21$; $p < 0.0001$), and cardiac valve replacement ($R = 0.20$; $p < 0.0001$). Whereas episodes

with the lowest degree of correlation included major joint replacement lower extremity ($R = 0.08$; $p < 0.0001$), CABG ($R = 0.09$; $p < 0.03$), spinal fusion ($R = 0.09$; $p < 0.005$), and major joint replacement upper extremity ($R = 0.09$; $p < 0.005$). All correlation measures were positive, or greater than zero, with the exception of double joint replacement lower extremity ($R = -0.05$; $p = 0.62$). Of the eleven acute episodes that were evaluated, nine of the correlation values were found to be significant at a level of $p<0.05$. Trends in the overall relationship for each acute episode were assessed using a LOESS smoothing plot (Figure 1).

Discussion

In this study looking at the association between patient EVCI score and corresponding 90-day episode expenditures, we found weak positive correlation across all episodes with the exception of one episode which indicated a negative correlation (Table 2). Within the eleven episodes assessed in this study, there were a range of correlation values observed, yet the highest correlation value was for Major Bowel Surgery ($R = 0.22$; $p < 0.0001$). Increases in EVCI score were expected to be associated with increased variation in episode expenditures, yet our findings demonstrated a weak association between these variables. While limited somewhat by our access to data and our statistical modeling, our findings shed light on the limitations of using comorbidity scores to interpret the variation in bundled payment expenditures. Our analysis was unable to provide additional insight into why certain episodes had a stronger correlation than others or what was mediating variation in expenditures.

While the correlation values indicate an overall weak association, observations from the LOESS plots (See Figure 1) provide some insight into the underlying non-linear relationship between

EVCI and 90-day episode expenditures highlighting an important observation. The relationship between EVCI and 90-day episode expenditures varies across different ranges of comorbidity score. For instance, in both CABG and heart failure episodes, at lower risk scores the LOESS plot is relatively flat, signifying limited correlation. At an EVCI score of 20-25 there is an inflection point in the respective curves, thereafter episode expenditures appear to be more closely associated with increases in EVCI score. In these cases, as the EVCI score increases it is better correlated with episode expenditures. One explanation for this observation is that at lower EVCI scores, patients with fewer comorbidities are less likely to have significant variation in their health care expenditures, and the EVCI may have less discriminative power in explaining variation in expenditures among these patients. Additional research is necessary to better characterize the differences between high and low EVCI score groups.

As hospitals and health care providers are held financially accountable for the longitudinal spending and outcomes of their patients, it is increasingly important to understand the risk of a given patient prospectively in order to optimize treatment plans while controlling for healthcare spending. Patient comorbidities remain an important variable to understand the variation in health care expenditures,[10,11] yet the weak correlation values demonstrated in our findings highlight other factors which also contribute to variation in health care expenditures. These findings are consistent with research from cardiac surgery, where a comorbidity-based risk score developed by the Society of Thoracic Surgery to predict risk of mortality (STS-PROM) following CABG surgery was found to explain only 28% of the variation in 90-day bundled payment expenditures for patients.[25] Though widely validated for patients requiring CABG surgery, the STS-PROM provided limited value in prospectively explaining patient expenditures.

More recent research is looking beyond a patient's comorbidities to understand the role that other factors play in spending variation such as social determinants of health, utilization of post-acute care services, and readmissions within thirty days following hospital discharge. Research studies investigating the role of social risk factors have found that patients' social needs including housing, disability, behavioral health needs, and payer status (Medicare, Medicaid, Dual-Eligible, etc.), have a significant impact on health spending variation to the point that policymakers are considering the inclusion of social factors in risk-adjustment methodology for Medicaid and Medicare payments.[26,27] Variation in healthcare spending in the period following hospitalization has also been highlighted as a key factor in spending variation.[28] A national study looking at variation in surgical episode payments in the Medicare population found that after controlling for comorbidities, post-discharge care and readmissions accounted for a significant proportion of variation observed in episode payments. These researchers also found differences between conditions, for example payment variation in hip replacement was explained mostly by post-discharge care, while for bowel surgery readmissions played a larger role.[29] Intuitively, patients requiring additional post-acute care services, or experiencing a readmission complication, are likely to have higher healthcare expenditures. Yet anticipating which patients are more likely to require post-acute care services or experience adverse outcomes can be difficult to determine and comorbidities may not offer much insight. For instance, in the case of joint replacement a study found that the EVCI poorly predicted a patient's post-acute discharge status or hospital readmission risk following surgery.[30] Health care providers may consider ways to incorporate patient social factors and predictors of post-acute care services and readmissions into population-level analytics in order to better understand variation in health spending.

Prior investigations of the relationship between comorbidity index scores and healthcare expenditures have similarly demonstrated limited association. An early study looking at how different comorbidity measures (not including the EVCI) predict healthcare expenditures in an outpatient setting found that the comorbidity measures provided poor to moderate predictive validity for health care expenses accrued over a one year period.[15] A later study within a managed care organization found that the Elixhauser comorbidity measure provided limited ability to predict healthcare expenditures for patients with hypertension over a one year period.[16] While patient comorbidities are an important factor in determining health care expenditures, the complex interplay of disease severity, social needs, physician decision-making, and post-discharge care make predictions of healthcare expenditures difficult. The simplicity of a comorbidity index is appealing to health care providers and hospital administrators looking to understand how patient populations will influence health care spending, yet comorbidity indexes appear unlikely to account for the many factors influencing health care spending variation. As bundled payments continue to take shape as an alternative payment methodology, hospitals and health care providers will need to integrate various data inputs to understand patient level variation in healthcare expenditures and manage their financial risk accordingly.

Limitations:

There are notable limitations to this study. Our study is primarily limited by data access. Without access to patient descriptive data our ability to construct more advanced statistical models with multivariate regression was limited. Other data limitations included our expenditure variable which was not broken into specific sub-categories of spending (i.e. inpatient, outpatient, SNF,

home health, etc.), thus limiting analysis into how expenditures vary across different sites of care and what areas of care are driving expenditure variation. To further focus on care expenditures in the post-discharge setting, excluding MS-DRG expenditures would allow greater insight into spending during this setting of care, however this was not attempted in our study. Our data also did not include mortality data for patients which could be influencing our results via the survival-expenditure bias.[31] For example, a patient with a high EVCI score who passes away during an episode would have a less expensive episode of care due to their passing. Excluding patients who pass away during an episode of care would mitigate this bias. Additionally, because our data was informed by claims, it is possible that patient comorbidities were not identified accurately or coded appropriately, which could alter the EVCI score of a patient. Lastly, the data was obtained from an academic integrated medical center in the Northeast, which may not be generalizable within other populations.

Conclusions

Despite being advanced as a key factor in understanding the variation in patient expenditures, our analysis found that a patient's EVCI comorbidity score is weakly associated with their 90-day bundled payment expenditures across multiple episodes of care. Additional research integrating comorbidity data with other important risk factors including social determinants, disease severity, readmission risk, and post-discharge care may provide additional insight for optimizing health care spending analytics.

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References

1. Cutler DM, Ghosh K. The potential for costs savings through bundled episode payments. *NEJM*. 2012;366:1075-1077.

2. Burwell S. Setting value-based payment goals – HHS efforts to improve U.S. health care. *NEJM*. 2015;372(10):897-899.

3. Press, M. J., Rajkumar, R., & Conway, P. H. Medicare's New Bundled Payment: Design, Strategy, and Evolution. *JAMA.* 2016; 315(2):131-132.

4. Centers for Medicare and Medicaid Studies. CMS finalizes changes to the Comprehensive Care for Joint Replacement Model, cancels Episode Payment Models and Cardiac Rehabilitation Incentive Payment Model. 2017. Available from: https://www.cms.gov/Newsroom/MediaReleaseDatabase/Press-releases/2017-Press-releases-items/2017-11-30.html

5. Dummit, L. A., Kahvecioglu, D., Marrufo, G., Rajkumar, R., Marshall, J., Tan, E., . . . Conway, P. H. Association between hospital participation in a Medicare bundled payment initiative and payments and quality outcomes for lower extremity joint replacement episodes. *JAMA. 2016;316*(12): 1267-1278.

6. Navathe, A. S., Troxel, A. B., Liao, J. M., Nan, N., Zhu, J., Zong, W., & Emanuel, E. Cost of joint replacement using bundled payment models. *JAMA: Internal Medicine.* 2017;177(2):214-222.

7. Mechanic, R., & Tompkins, C. Lessons learned preparing for Medicare bundled payments. *New England Journal of Medicine.* 2012;367(20):1873-1875.

8. Ridgeley, S. M. Bundled payment fails to gain foothold in California: The experience of the IHA bundled payment demonstration. *Health Affairs.* 2014;33(8): 1345-1352.

9. Hussey, P. S., Ridgely, M. S., & Rosenthal, M. B. The PROMETHEUS bundled payment experiment: slow start shows problems in implementing new payment models. *Health Affairs.* 2001;30(11): 2116-2124.

10. Altman, S. H. The lessons of Medicare's prospective payment system show that the bundled payment program faces challenges. *Health Affairs*. 2012;31(9): 1923-1930.

11. Tsai TC, Miller DC. Bundling payments for episodes of surgical care. *JAMA: Surgery*. 2015; 150(9):905-906.

12. Vogeli C, Shield AE, Lee TA, Gibson TB, Marder WD, Weiss KB, Blumenthal D. Multiple chronic conditions: Prevalence, health consequences, and implications for quality, care management, and costs. *JGIM*. 2007;22(3):391-395.

13. Walraven C, Austin PC, Jennings A, Quan H, Forster AJ. A modification of the Elixhauser comorbidity measures into a point system for hospital death using administrative data. *Medical Care*. 2009;47(6):626-633.

14. Sharabiana MTA, Aylin P, Bottle A. Systematic review of comorbidity indices for administrative data. *Medical Care*. 2012;50:1109-18.

15. Quan H, Sundararajan V, Galfon P, Fong A, Burnand B, Luthi JC, Saunders LD, Beck CA, Feasby TE, Ghali WA. Coding algorithms for defining comorbidities in ICD-9-CM and ICD-10 administrative data. *Medical Care*. 2005;43(11):1130-1139.

16. Elixhauser A, Steiner C, Harris DR, Coffey RM. Comorbidity measures for use with administrative data. *Medical Care*. 1998;36:8-27.

17. Ladha, K. S. The Deyo-Charlson and Elixhauser-Van Walraven Comorbidity Indices as predictors of mortality in critically ill patients. *BMJ Open.* 2015;*5.9*, e008990.

18. Li P, Kim MM, Doshi JA. Comparison of the performance of the CMS Hierarchical Condition Category (CMS-HCC) risk adjuster with the Charlson and Elixhauser comorbidity measures in predicting mortality. *BMC Health Services Research*. 2010;10:245.

19. Centers for Medicare and Medicaid Services. Bundled Payments for Care Improvement initiative. Baltimore MD. [cited 2016 Jan 8]. Available from: http:// innovation.cms.gov/initiatives/ bundled-payments/

20. Centers for Medicare and Medicaid Studies. Method A Episode Grouper for Medicare (EGM): Design Report. 2016. Available from: https://www.cms.gov/Medicare/Quality-Initiatives-Patient-Assessment-Instruments/Value-Based-Programs/MACRA-MIPS-and-APMs/EGM-Design-Report.pdf

21. Centers for Medicare and Medicaid Studies. Design and development of the Diagnosis Related Group (DRG). 2016. Available from: https://www.cms.gov/ICD10Manual/version34-fullcode-cms/fullcode_cms/Design_and_development_of_the_Diagnosis_Related_Group_(DRGs)_PBL-038.pdf

22. Cleveland WS, Devlin SJ, Grosse E. Regression by local fitting:Methods, properties, and computational algorithms. *Journal of Econometrics*. 1988;37(1):87-114.

23. Yount KW, Isbel JM, Lichtendahl C, Dietch Z, Ailawadi G, Kron IL, Kern JA, Lau CL. Bundled payments in cardiac surgery: Is risk adjustment sufficient to make it feasible? *Annals of Thoracic Surgery*. 2015;100:1646-1652.

24. Ash AS, Mick EO, Ellis RP, Kiefe CI, Allison JJ, Clark MA. Social determinants of health in managed care payment formulas. *JAMA: Internal Medicine*. 2017;177(10):1424-1430.

25. Joynt KE, De Lew N, Sheingold SH, Conway PH, Goodrich K, Epstein AM. Should Medicare value-based purchasing take social risk into account. *New England Journal of Medicine*. 2017; 376:510-513.

26. Huckfeldt PJ, Mehrotra A, Hussey PS. Relative importance of post-acute care and readmissions for post-discharge spending. Health Services Research. 2016;51(5):1919-1938

27. Miller DC, Gust C, Dimick JB, Birkmeyer N, Skinner J, Birkmeyer JD. Large variations in Medicare payments for surgery highlights savings potential from bundled payment programs. *Health Affairs*. 2011;30(11):2107-2115.

28. Kumar A, Karmarkar A, Downer B, Vashist A, Adhikari D, Snih SA, Ottenbacher K. Current risk adjustment and comorbidity index underperformance in predicting post-acute utilization and hospital readmissions after joint replacemnts: Implications for Comprehensive Care for Joint Replacement Model. *Arthritis Care & Research*. 2017;69(11):1668-1675.

29. Perkins AJ, Kroenke K, Unutzer J, Katon W, Williams JW, Hope C, Callahan CM. Common comorbidity scales were similar in their ability to predict health care costs and mortality. *Journal of Clinical Epidemiology*. 2004;57(10):1040-1048.

30. Farley JF, Harley CR, Devine JW. A comparison of comorbidity measurements to predict healthcare expenditures. *AJMC*. 2006;12:110-117.

31. Cohen D, Manuel DG, Tugwell P, Sanmartin C, Ramsay T. Does Higher Spending Improve Survival Outcomes for Myocardial Infarction? Examining the Cost-Outcomes Relationship Using Time-Varying Covariates. Health Serv Res. 2015;50(5):1589-1605.

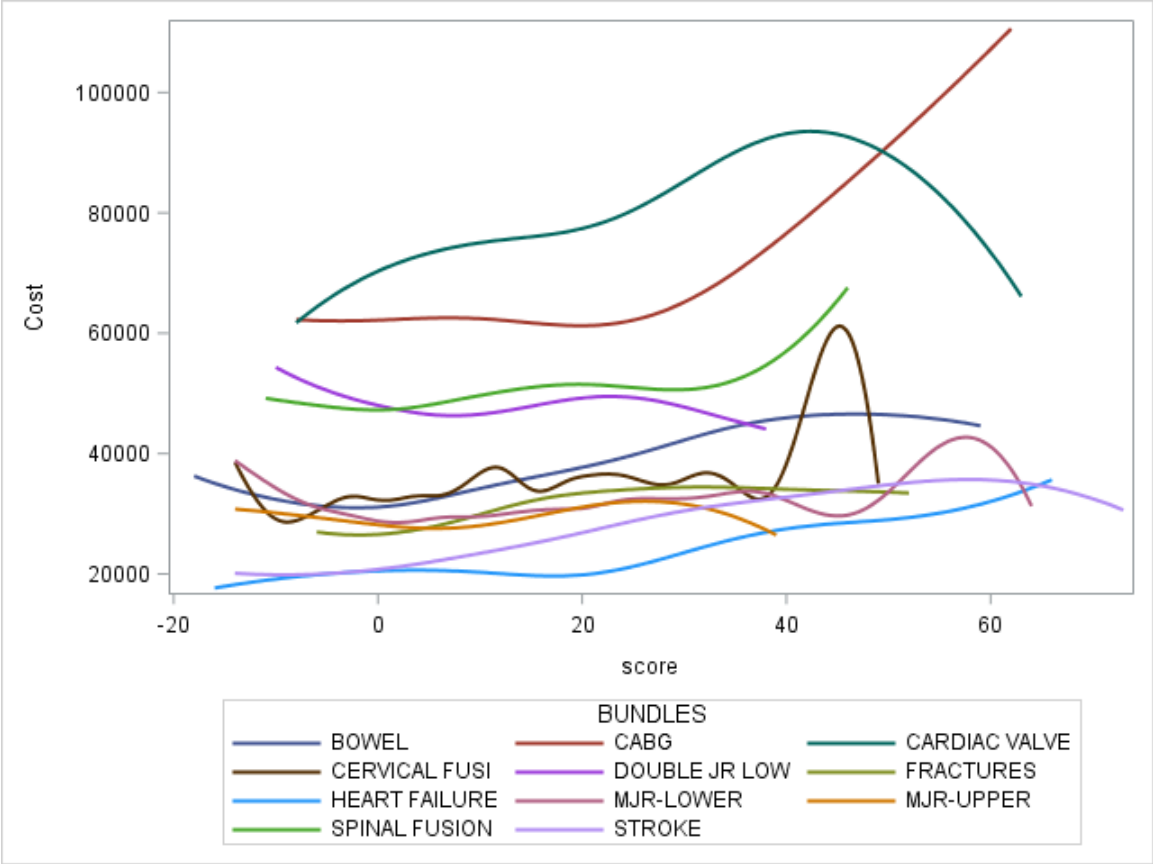
Table 1: Episodes of Care Characteristics

Bundled Payment Episode	Number of Episodes	Average EVCI score	EVCI Standard Deviation	Average 90-day Bundled Payment Cost ($)	90-day Bundled Payment Standard Deviation ($)
Major Bowel Surgery	1,543	13.89	12.66	35,863	19,507
CABG	544	14.02	10.45	62,746	20,935
Cardiac Valve	769	18.16	11.21	77,936	25,305
Cervical Fusion	497	7.38	11.12	33,951	13,440
Double Joint Replacement Lower Extremity	102	6.88	9.92	47,459	15,850
Fractures	280	15.43	11.12	30,429	15,100
Heart Failure	2,303	23.19	12.25	22,317	12,119
Major Jt. Replacement: Lower Ext	7,264	7.55	9.67	29,820	8,565
Major Jt. Replacement: Upper Ext	330	7.42	9.55	28,741	7,247
Spinal Fusion	969	7.50	9.76	48,759	18,093
Stroke	1,540	17.30	12.27	25,879	17,562

Table 2: Association between EVCI comorbidity score and bundled payment costs

Bundled Payment Episode	**Correlation Coefficient**	**P Value**
Major Bowel Surgery	0.22	$p < 0.0001$
Stroke	0.21	$p < 0.0001$
Cardiac Valve	0.20	$p < 0.0001$
Fractures	0.17	$p = 0.0043$
Heart Failure	0.16	$p < 0.0001$
Cervical Fusion	0.15	$p = 0.0009$
Major Jt. Replacement: Upper Ext	0.09	$p = 0.080$
CABG	0.09	$p = 0.03$
Spinal Fusion	0.09	$p = 0.0050$
Major Jt. Replacement: Lower Ext	0.08	$p <0.0001$
Double Joint Replacement Lower Extremity	-0.05	$p = 0.62$

Figure 1: LOESS plot of association between patient EVCI comorbidity score and 90-day episode expenditures for eleven episodes of care



Appendix:

Table 1a: Comorbidities included in the Elixhauser-Van Walraven Comorbidity Index[13]

Elixhauser –van Walraven Comorbidities	**Points**
HIV/AIDS	0
Alcohol abuse	0
Blood loss/Anemia	-2
Cardiac arrhythmias	5
Chronic pulmonary disease	3
Coagulopathy	3
Congestive heart failure	7
Deficiency/Anemia	-2
Depression	-3
Diabetes complicated	0
Diabetes uncomplicated	0
Drug abuse	-7
Fluid and electrolytes disorders	5
Hypertension	0
Hypothyroidism	0
Liver disease	11
Lymphoma	9
Metastatic cancer	12
Neurodegenerative disorders	6
Paralysis	7
Peptic ulcer disease (excluding bleeding)	0
Peripheral vascular disease	2
Psychoses	0
Pulmonary circulation disorders	4
Renal failure	5
Rheumatoid disorders	0
Solid tumor without metastasis	4
Valvular heart disease	-1
Weight loss	6
Obesity	-4