



Disparity Implications of Machine-Learning-Based MTM Eligibility Criteria

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BACKGROUND

- Medicare Medication Therapy Management (MTM) programs improve clinical and economic outcomes,^{1,2} but racial/ethnic minority groups face challenges meeting eligibility criteria for enrollment.³
- The Centers for Medicare and Medicaid Services (CMS) launched the Enhanced MTM demonstration in 2017, granting Part D plans flexibility in identifying eligible beneficiaries.⁴
- Participating plans adopted predictive modeling to determine eligibility, but concerns remain that this approach may perpetuate racial/ethnic disparities.

OBJECTIVES

To assess racial/ethnic differences in cost-based MTM eligibility and whether machine learning models reproduce observed disparities in predicted eligibility.

METHODS

- Study design:** A retrospective, cross-sectional analysis of 2019 Medicare Parts A, B, and D data linked to the Area Health Resource Files.
- Study sample:**
 - Inclusion criteria: (1) 2019 Medicare fee-for-service beneficiaries; (2) continuous enrollment in Parts A, B, and D for the full year; (3) alive at the end of 2019; (4) non-missing data on study variables.
 - 10% random sample of qualifying beneficiaries.
- Conceptual framework:** Gelberg-Anderson's Behavioral Model for Vulnerable Populations.⁵
- Outcome:** Binary indicators of top-quartile medication and healthcare costs, based on cost domains used in Enhanced MTM and CMS expectations for enrollment.^{4,6}
 - Medicare perspective: Medicare reimbursement.
 - Healthcare system perspective: total expenditure from all payment sources.
- Data Analysis:**
 - Descriptive analysis:
 - Compare patient characteristics and outcomes across racial/ethnic groups.
 - t-tests for continuous variables and chi-square tests for categorical variables.
 - Regression and machine learning analysis:
 - Two-stage approach: (1) multivariable logistic regression to assess observed racial/ethnic disparities in the total sample; (2) machine learning models to generate predicted probabilities, followed by regression analysis using the test set to evaluate disparities in predicted outcomes.
 - Machine learning models: regularized logistic regression, random forest, gradient boosted trees, multi-layer perceptron neural network, support vector machine, and consensus (soft voting across models); total sample split into 75% training and 25% test sets (stratified by race/ethnicity).
 - Machine learning performance was assessed using standard metrics, with 95% confidence intervals estimated via nonparametric bootstrapping.
 - Predicted probabilities generated from machine learning were analyzed using multivariable fractional logistic regression.

RESULTS

- Racial/ethnic minority groups differed from non-Hispanic White (White) beneficiaries in patient characteristics, with Black and Hispanic individuals having less favorable socioeconomic attributes and higher clinical risk (Table 1).
- Racial/ethnic differences were observed in top-quartile cost outcomes, with Black and Hispanic beneficiaries having higher proportions in the top quartile across all cost measures than their White counterparts (Table 2).
- After covariate adjustment, Black and Hispanic beneficiaries had lower odds of top-quartile cost inclusion than White beneficiaries across all outcomes, with similar patterns observed for other minority groups in healthcare costs (Table 3).
- Machine learning models demonstrated strong predictive performance across all cost outcomes, with high discrimination and adequate calibration (Table 4).
- Predicted probabilities from machine learning models generally reflected observed disparities, with consistent direction of associations and statistical significance for Black and Hispanic groups across all outcomes (Table 5).

TABLES/FIGURES

Characteristics	Non-Hispanic White (n = 1,489,202; 80.56%)	Black (n = 148,439; 8.03%)	Hispanic (n = 101,492; 5.49%)	Asian/Pacific Islander (n = 53,252; 2.88%)	Other (n = 56,269; 3.04%)
Predisposing factors					
Age, mean (SD)	73.05 (11.21)	66.52* (15.01)	69.45* (14.13)	74.40* (11.15)	68.50* (12.03)
Male, n (%)	624,421 (41.93)	59,985* (40.41)	43,136 (42.50)	22,091 (41.48)	31,193* (55.44)
Original reason for Medicare enrollment, n (%)					
OASI	1,172,262 (78.72)	71,477* (48.15)	62,269* (61.35)	45,408* (85.27)	43,539* (77.38)
DIB	312,455 (20.98)	72,022 (48.52)	36,733 (36.19)	7,247 (13.61)	12,198 (21.68)
ESRD	2,339 (0.16)	2,390 (1.61)	1,378 (1.36)	354 (0.66)	315 (0.56)
DIB and ESRD	2,146 (0.14)	2,550 (1.72)	1,112 (1.10)	243 (0.46)	217 (0.39)
Low-income subsidy, n (%)	323,143 (21.70)	92,083* (62.03)	69,109* (68.09)	30,393* (57.07)	16,922* (30.07)
Percentage of non-White population, mean (SD)	30.91 (19.31)	47.84* (18.25)	55.68* (21.92)	54.82* (18.79)	38.09* (21.54)
Proportion of married-couple families, mean (SD)	72.26 (6.11)	65.37* (7.96)	68.39* (6.30)	70.35* (6.24)	71.26* (7.01)
Proportion with education ≥ high school, mean (SD)	88.70 (4.70)	86.96* (4.70)	83.88* (7.37)	87.24 (5.21)	88.70 (4.77)
Per capita income (in \$1,000), mean (SD)	54.94 (18.84)	54.57 (19.59)	57.66 (23.21)	70.35* (26.14)	58.87* (22.49)
Proportion without health insurance, mean (SD)	10.35 (4.65)	11.11* (4.52)	12.58* (6.55)	9.15* (4.21)	10.30 (4.82)
Enabling factors					
Metropolitan statistical area, n (%)	1,134,395 (76.17)	126,263* (85.06)	90,419* (89.09)	51,177* (96.10)	44,437* (78.97)
Health Professional Shortage Area, n (%)	1,361,244 (91.41)	142,215* (95.81)	98,080* (96.64)	50,300 (94.46)	52,314* (92.97)
Census region, n (%)					
Northeast	299,908 (20.14)	23,150* (15.60)	17,698* (17.44)	9,467* (17.78)	12,317* (21.89)
Midwest	380,850 (25.57)	27,478 (18.51)	9,655 (9.51)	5,455 (10.24)	12,140 (21.57)
South	547,232 (36.75)	86,451 (58.24)	32,682 (32.20)	10,455 (19.63)	16,114 (28.64)
West	261,212 (17.54)	11,360 (7.65)	41,457 (40.85)	27,875 (52.35)	15,698 (27.90)
Need factor					
Risk adjustment summary score, mean (SD)	1.22 (1.19)	1.56* (1.69)	1.45* (1.50)	1.26 (1.22)	1.08* (1.19)

Abbreviations: SD = standard deviation; OASI = old age and survivors insurance; DIB = disability insurance benefits; ESRD = end-stage renal disease. * Indicates a statistically significant difference from non-Hispanic White patients (P < 0.05).

TABLES/FIGURES

Costs	Outcome	Non-Hispanic White, n (%)	Black, n (%)	Hispanic, n (%)	Asian/Pacific Islander, n (%)	Other, n (%)
Total medication	No	1,130,401 (75.91)	104,421 (70.35)	71,269 (70.22)	37,437 (70.30)	42,962 (76.35)
	Yes	358,801 (24.09)	44,018* (29.65)	30,223* (29.78)	15,815* (29.70)	13,307 (23.65)
Total healthcare	No	1,125,811 (75.60)	102,469 (69.03)	72,649 (71.58)	41,537 (78.00)	44,024 (78.24)
	Yes	363,391 (24.40)	45,970* (30.97)	28,843* (28.42)	11,715 (22.00)	12,245* (21.76)
Medicare medication	No	1,138,726 (76.47)	100,510 (67.71)	68,209 (67.21)	36,184 (67.95)	42,860 (76.17)
	Yes	350,476 (23.53)	47,929* (32.29)	33,283* (32.79)	17,068* (32.05)	13,409 (23.83)
Medicare healthcare	No	1,129,184 (75.82)	101,049 (68.07)	71,336 (70.29)	40,872 (76.75)	44,049 (78.28)
	Yes	360,018 (24.18)	47,390* (31.93)	30,156* (29.71)	12,380 (23.25)	12,220* (21.72)

* Indicates frequency distribution was significantly different from non-Hispanics White (p < .05).

Table 3. Multivariable-adjusted patterns of racial/ethnic disparities in top-quartile inclusion for cost outcomes among total study population

Race/ethnicity	Total medication		Total healthcare		Medicare medication		Medicare healthcare	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Black	0.72	0.70–0.75	0.85	0.83–0.87	0.71	0.69–0.74	0.84	0.82–0.86
Hispanic	0.79	0.74–0.84	0.80	0.75–0.85	0.78	0.73–0.83	0.79	0.74–0.84
Asian/Pacific Islander	1.03	0.92–1.15	0.70	0.66–0.75	1.03	0.92–1.16	0.71	0.66–0.77
Other	0.99	0.95–1.03	0.94	0.91–0.97	0.99	0.95–1.03	0.93	0.90–0.96

Abbreviations: OR = odds ratio; CI = confidence interval. Covariates: Age, gender, reason for Medicare enrollment, low-income subsidy, community-level population characteristics, non-metropolitan statistical area, Health Professional Shortage Area, census region, and risk adjustment summary score.

Table 4. Model performance metrics for predicting the likelihood of being in the top quartile of cost outcomes

Outcomes/machine learning models	Prediction accuracy		AUC-ROC		Brier score		AUC-PR	
	PE	95% CI	PE	95% CI	PE	95% CI	PE	95% CI
Total medication								
Regularized logistic	0.7849	0.7838–0.7861	0.7989	0.7975–0.8002	0.1480	0.1473–0.1486	0.5683	0.5650–0.5713
Random forest	0.7730	0.7719–0.7743	0.7963	0.7949–0.7978	0.1526	0.1521–0.1531	0.5586	0.5555–0.5618
Gradient boosted trees	0.7888	0.7877–0.7900	0.8079	0.8066–0.8094	0.1433	0.1427–0.1438	0.5897	0.5867–0.5928
MLPNN	0.7864	0.7852–0.7876	0.8065	0.8052–0.8079	0.1443	0.1437–0.1448	0.5802	0.5770–0.5834
Support vector machine	0.7820	0.7808–0.7832	0.7891	0.7876–0.7905	0.1502	0.1496–0.1509	0.5561	0.5529–0.5591
Consensus	0.7863	0.7852–0.7876	0.8055	0.8041–0.8069	0.1454	0.1448–0.1460	0.5793	0.5762–0.5825
Total healthcare								
Regularized logistic	0.7984	0.7972–0.7996	0.7917	0.7901–0.7931	0.1440	0.1434–0.1446	0.6062	0.6033–0.6091
Random forest	0.7853	0.7841–0.7865	0.7837	0.7821–0.7853	0.1509	0.1503–0.1515	0.5906	0.5875–0.5934
Gradient boosted trees	0.8000	0.7989–0.8012	0.7951	0.7935–0.7965	0.1423	0.1417–0.1429	0.6140	0.6111–0.6167
MLPNN	0.7987	0.7976–0.7999	0.7933	0.7917–0.7948	0.1434	0.1428–0.1440	0.6055	0.6026–0.6085
Support vector machine	0.7961	0.7950–0.7972	0.7871	0.7856–0.7887	0.1455	0.1449–0.1461	0.5986	0.5957–0.6014
Consensus	0.7987	0.7976–0.7999	0.7937	0.7922–0.7953	0.1435	0.1429–0.1441	0.6093	0.6064–0.6123
Medicare medication								
Regularized logistic	0.7969	0.7957–0.7981	0.8167	0.8153–0.8181	0.1409	0.1402–0.1415	0.6061	0.6031–0.6093
Random forest	0.7834	0.7822–0.7846	0.8146	0.8133–0.8160	0.1469	0.1464–0.1475	0.5987	0.5956–0.6018
Gradient boosted trees	0.8014	0.8003–0.8025	0.8270	0.8257–0.8282	0.1364	0.1358–0.1370	0.6281	0.6252–0.6309
MLPNN	0.8000	0.7988–0.8012	0.8264	0.8251–0.8277	0.1370	0.1364–0.1376	0.6221	0.6191–0.6252
Support vector machine	0.7944	0.7932–0.7956	0.8074	0.8060–0.8088	0.1432	0.1426–0.1438	0.5933	0.5902–0.5964
Consensus	0.7988	0.7977–0.7999	0.8242	0.8229–0.8255	0.1383	0.1378–0.1389	0.6195	0.6164–0.6222
Medicare healthcare								
Regularized logistic	0.8004	0.7994–0.8015	0.7930	0.7915–0.7945	0.1429	0.1423–0.1435	0.6127	0.6097–0.6155
Random forest	0.7874	0.7862–0.7885	0.7852	0.7838–0.7868	0.1500	0.1494–0.1506	0.5992	0.5964–0.6020
Gradient boosted trees	0.8025	0.8014–0.8036	0.7976	0.7961–0.7991	0.1411	0.1405–0.1418	0.6217	0.6188–0.6246
MLPNN	0.8013	0.8002–0.8025	0.7959	0.7942–0.7973	0.1419	0.1413–0.1425	0.6158	0.6129–0.6186
Support vector machine	0.7967	0.7955–0.7978	0.7898	0.7883–0.7915	0.1448	0.1442–0.1455	0.6016	0.5985–0.6043
Consensus	0.8009	0.7998–0.8020	0.7960	0.7945–0.7975	0.1424	0.1418–0.1430	0.6168	0.6139–0.6196

Abbreviations: AUC-ROC = Area under Curve - receiver operating characteristic; AUC-PR = Area under curve - precision-recall; PE = point estimate; CI = confidence interval; MLPNN = multi-layer perceptron neural network.

TABLES/FIGURES

Table 5. Multivariable-adjusted racial/ethnic disparity patterns in the predicted probabilities of top-quartile inclusion for cost outcomes based on the consensus model

Race/ethnicity	Total medication		Total healthcare		Medicare medication		Medicare healthcare	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Black	0.83	0.82–0.84	0.92	0.91–0.93	0.81	0.80–0.82	0.916	0.909–0.923
Hispanic	0.88	0.87–0.89	0.88	0.87–0.89	0.87	0.85–0.88	0.88	0.87–0.89
Asian/Pacific Islander	1.05	1.03–1.08	0.80	0.79–0.82	1.06	1.03–1.09	0.82	0.80–0.83
Other	0.99	0.98–1.01	0.97	0.96–0.98	1.001	0.986–1.016	0.97	0.96–0.98

Abbreviations: OR = odds ratio; CI = confidence interval. Covariates: Age, gender, reason for Medicare enrollment, low-income subsidy, community-level population characteristics, non-metropolitan statistical area, Health Professional Shortage Area, census region, and risk adjustment summary score.

STUDY LIMITATIONS

- Limited clinical detail and lack of direct measures of social determinants of health in the study may result in residual confounding.
- The analysis focused on cost-based MTM eligibility criteria, excluding other plan-specific eligibility factors such as medication use and chronic conditions.
- Top-quartile cost threshold may not reflect actual eligibility cutoffs used by Medicare Part D plans.
- The findings are limited to fee-for-service Medicare beneficiaries, reducing generalizability to other populations.
- Plan-level variation in MTM implementation, including outreach and enrollment practices, was not captured in the analysis.

CONCLUSIONS

- Cost-based MTM eligibility criteria were associated with racial/ethnic disparities, with Black and Hispanic beneficiaries less likely to meet high-cost thresholds after adjusting for patient characteristics.
- Machine learning models reproduced these disparities, indicating that predictive approaches may perpetuate existing disparity patterns in health spending.
- Reliance on cost-based or algorithm-driven eligibility may limit access to MTM services for certain racial/ethnic minority populations.
- Alternative eligibility criteria that incorporate clinical and social factors may help improve equitable identification of high-need beneficiaries.

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