Online Appendices

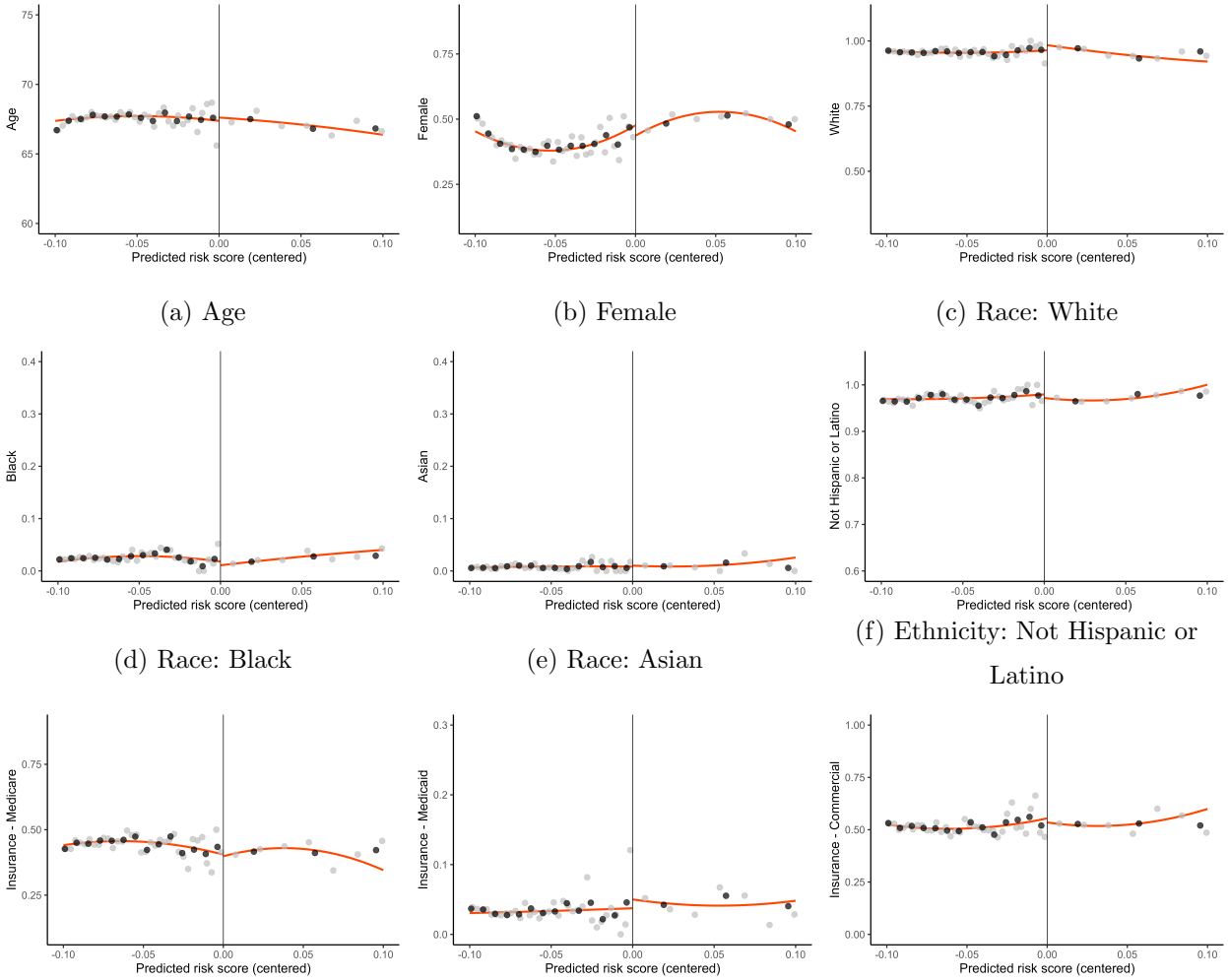
Online Appendix A: Sampling Steps

Table OA.1 Detailed Sampling Steps

	Sampling step	Sample size after each sampling step
1	Risk scores collected from July 2019 to December 2022	72,369
2	Exclude flagged risk scores of patients who had a colonoscopy before the outreach	72,364
3	Exclude flagged risk scores that were not outreached after a chart review (because, for example, the patient was deceased or admitted to the hospital)	72,094
4	Exclude risk scores of patients who are aged 50	69,482
5	For patients with multiple risk scores, limit one risk score per each month per patient (include only the patient's highest risk score in each month)	62,485 Treated: 1,521 Control: 60,964

Online Appendix B: Figures with Quadratic Regressions

Figure OA.1 Balance of Predetermined Characteristics with Quadratic Regressions



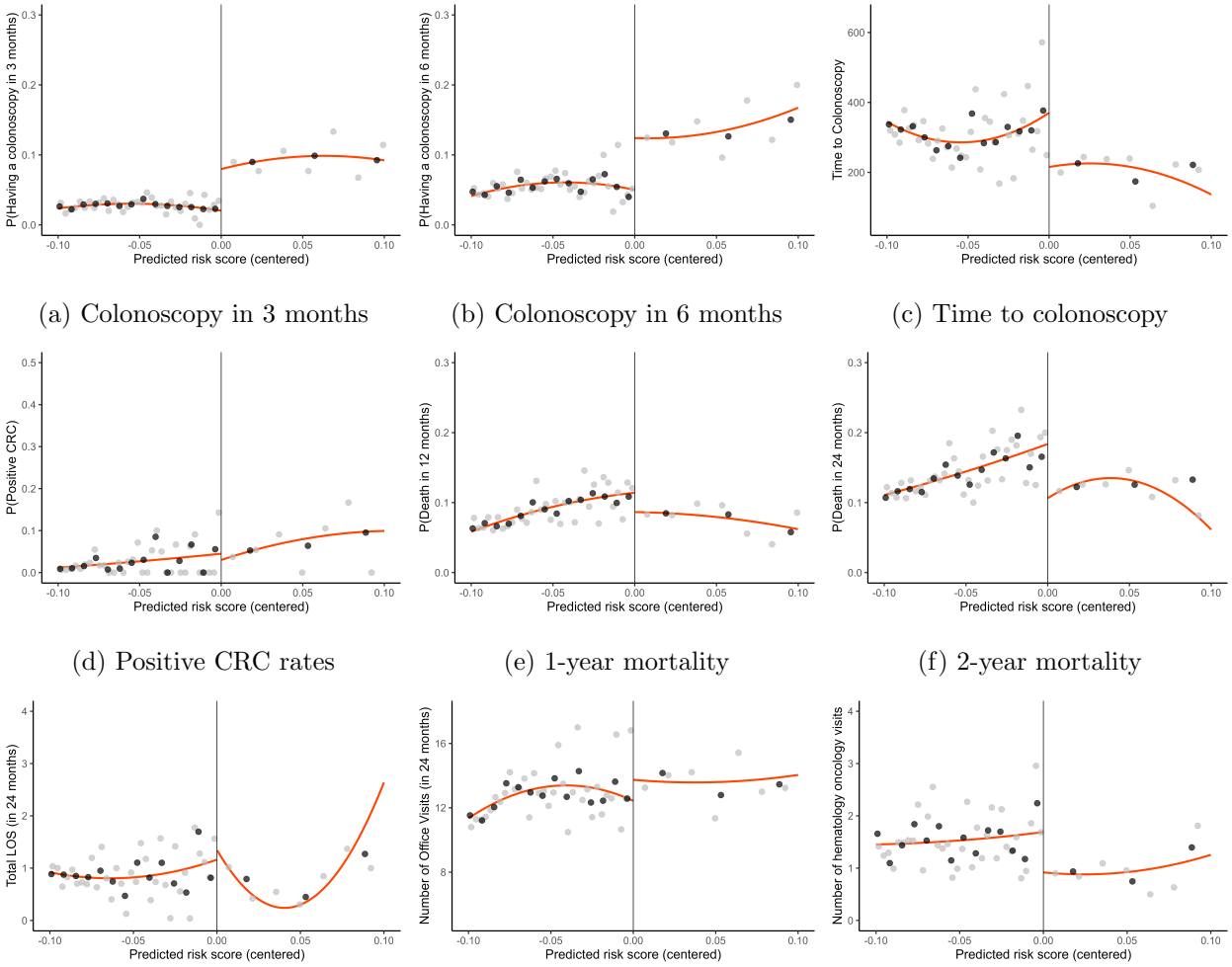
(a) Age (b) Female (c) Race: White

(d) Race: Black (e) Race: Asian (f) Ethnicity: Not Hispanic or Latino

(g) Insurance: Medicare (h) Insurance: Medicaid (i) Insurance: Commercial

Notes. The figure plots the characteristics of the sample. Black points present the average value of the specified variable for risk scores with 20 bins on each side of the cutoff. Gray points present the average value of the specified variable for risk scores with 50 bins on each side of the cutoff. The solid vertical line represents the cutoff risk score value. The solid, red trend lines are the predicted values from local quadratic regression fits of the specified variable on the score, fitted separately above and below the cutoff, that uses a triangular kernel and a bandwidth of 0.10 on each side.

Figure OA.2 RD Plots with Quadratic Regressions



(a) Colonoscopy in 3 months (b) Colonoscopy in 6 months (c) Time to colonoscopy

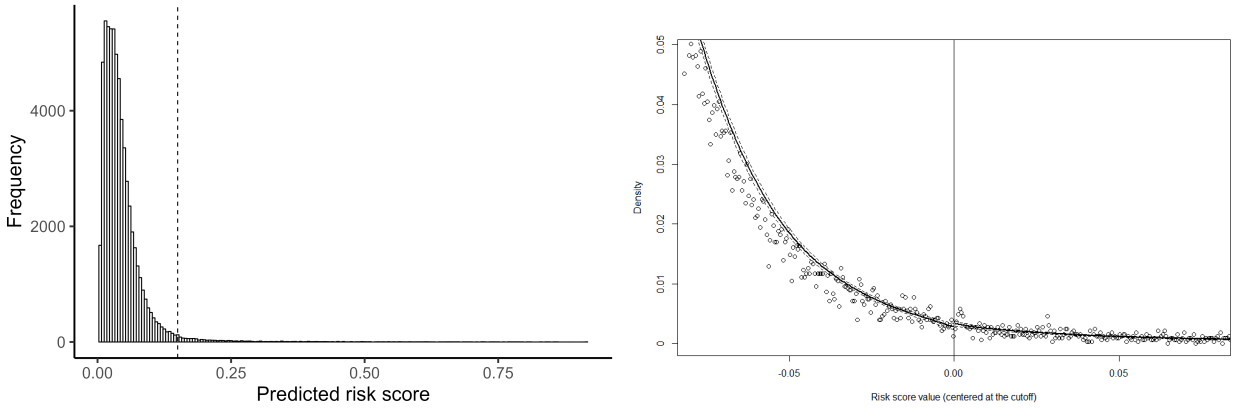
(d) Positive CRC rates (e) 1-year mortality (f) 2-year mortality

(g) Inpatient LOS in 2 years (h) Office visits in 2 years (i) Hematology oncology office visits in 2 years

Notes. Black points present the average value of the specified variable for risk scores with 20 bins on each side of the cutoff. Gray points present the average value of the specified variable for risk scores with 50 bins on each side of the cutoff. The solid vertical line represents the cutoff risk score value. The solid, red trend lines are the predicted values from local quadratic regression fits of the specified variable on the score, fitted separately above and below the cutoff, that uses a triangular kernel and a bandwidth of 0.10 on each side. CRC: colorectal cancer, LOS: length of stay.

Online Appendix C: Distribution of Risk Score

Figure OA.3 Density of Running Variable



(a) Distribution of risk score (b) McCrary (2008) test

Notes. Panel (a) shows the distribution of predicted risk score for the entire range, with a bin width of 0.005. Panel (b) shows the densities computed over bins with a width of 0.0005, around the cutoff point. The line plots a nonparametric regression to each side of the distribution following McCrary (2008), testing for a discontinuity at zero. The test fails to reject the null hypothesis of no discontinuity in the density at the cutoff (p-value $= 0.154$).

Online Appendix D: Analysis of Inpatient LOS by Specialty

Table OA.2 Effects on Inpatient LOS by Specialty at the Cutoff

Outcome	2-year LOS			
Specialty	ICU	Medical/Surgical	Oncology	Radiology
	(1)	(2)	(3)	(4)
Panel A. Local linear regression				
Flag	-0.177	0.125	-0.075	0.003
	(0.174)	(0.875)	(0.065)	(0.002)
Controls	Yes	Yes	Yes	Yes
Bandwidth (interval)	[-0.045, 0.032]	[-0.062, 0.073]	[-0.077, 0.096]	[-0.077, 0.096]
Mean below cutoff	0.111	0.515	0.180	0.004
Observations	682	1,246	2,016	2,016
Panel B. Local quadratic regression				
Flag	0.036	0.197	-0.006	0.001
	(0.185)	(1.038)	(0.061)	(0.003)
Controls	Yes	Yes	Yes	Yes
Bandwidth (interval)	[-0.034, 0.061]	[-0.081, 0.120]	[-0.100, 0.145]	[-0.100, 0.145]
Mean below cutoff	0.157	0.484	0.163	0.005
Observations	535	2,340	4,523	4,523

Notes. Panels A and B present the estimates using local linear regression and local quadratic regression, respectively, with a triangular weighting kernel. Control variables include age, sex, and race. Bandwidth shows the interval centered around the cutoff point, 0.150, using MSE optimal bandwidths (Calonico et al. 2014). For columns 3 and 4, MSE optimal bandwidths cannot be calculated due to too many zero values; we use the bandwidths in Table 4 column 5 and column 6. The observations row shows effective observations within the bandwidth. Robust standard errors are reported in parentheses. Total observations: 15,633 include Geisinger Health Plan holders with risk scores collected until December 2021. $^{*}p < 0.05, ^{**}p < 0.01, ^{***}p < 0.001$.

Online Appendix E: Analysis of Office Visits by Specialty

Table OA.3 Effects on 2-year Office Visits by Relevant Specialty at the Cutoff

Outcome	Number of visits in 2 years			
Specialty	Family Medicine	General Surgery	Internal Medicine	Radiation Oncology
	(1)	(2)	(3)	(4)
Panel A. Local linear regression				
Flag	0.245	0.286	-0.006	0.025
	(0.620)	(0.153)	(0.183)	(0.128)
Controls	Yes	Yes	Yes	Yes
Bandwidth (interval)	[-0.075, 0.097]	[-0.041, 0.085]	[-0.043, 0.146]	[-0.036, 0.085]
Mean below cutoff	4.485	0.158	0.306	0.146
Observations	1,885	710	806	621
Panel B. Local quadratic regression				
Flag	0.235	0.281	-0.005	0.067
	(0.724)	(0.174)	(0.220)	(0.151)
Controls	Yes	Yes	Yes	Yes
Bandwidth (interval)	[-0.087, 0.159]	[-0.052, 0.159]	[-0.070, 0.204]	[-0.055, 0.105]
Mean below cutoff	4.466	0.207	0.290	0.153
Observations	2,861	1,039	1,699	1,065

Notes. Panels A and B present the estimates using local linear regression and local quadratic regression, respectively, with a triangular weighting kernel. Control variables include age, sex, and race. Bandwidth shows the interval centered around the cutoff point, 0.150, using MSE optimal bandwidths (Calonico et al. 2014). The observations row shows effective observations within the bandwidth. Robust standard errors are reported in parentheses. Total observations: 15,633 include Geisinger Health Plan holders with risk scores collected until December 2021. $^{*}p < 0.05$,$^{**}p < 0.01$,$^{***}p < 0.001$.

Online Appendix F: Placebo Outcomes

Table OA.4 Effects on Unrelated Outcomes

Outcome	2-year LOS: Orthopedics		2-year LOS: Psychiatry	
	Linear	Quadratic	Linear	Quadratic
	(1)	(2)	(3)	(4)
Flag	0.001	-0.010	-0.017	-0.021
	(0.019)	(0.026)	(0.016)	(0.021)
Controls	Yes	Yes	Yes	Yes
Mean below cutoff	0.003	0.003	0.018	0.010
Observations	1,091	2,152	1,091	2,152

Notes. The table presents the estimates using local linear regression (columns 1 and 3) and local quadratic regression (columns 2 and 4). Control variables include age, sex, and race. Robust standard errors are reported in parentheses. We use the bandwidths in Table 5 column 1 and column 2 because MSE optimal bandwidths cannot be calculated due to too many zero values. As Table 5, analyses include Geisinger Health Plan holders with risk scores collected until December 2021 (Total observations: 15,633). $^{+}p < 0.1$,$^{*}p < 0.05$,$^{**}p < 0.01$,$^{***}p < 0.001$.

Online Appendix G: Robustness to Different Kernels

Table OA.5 Effects on Colonoscopy Uptake and Mortality at the Cutoff Using Different Kernels

Outcome	Colonoscopy in 3 months				2-year mortality			
Kernels	Uniform		Epanechnikov		Uniform		Epanechnikov	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Flag	0.053**	0.050*	0.063**	0.061**	-0.087**	-0.080*	-0.068*	-0.075*
	(0.019)	(0.024)	(0.019)	(0.021)	(0.033)	(0.035)	(0.028)	(0.035)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bandwidth (interval)	[-0.042, 0.070]	[-0.050, 0.093]	[-0.068, 0.063]	[-0.090, 0.108]	[-0.053, 0.039]	[-0.086, 0.093]	[-0.080, 0.068]	[-0.107, 0.086]
Mean below cutoff	0.025	0.029	0.029	0.029	0.150	0.138	0.140	0.121
Observations	2,622	3,449	5,803	13,072	2,753	8,520	6,958	17,759
Control	1,834	2,549	5,058	12,103	2,304	7,824	6,356	17,086
Treated	788	900	745	969	449	696	602	673

Notes. The table presents the estimate using uniform and Epanechnikov kernel functions. Control variables include age, sex, race, and insurance type (Medicare, Medicaid, military, commercial, self-pay). Bandwidth shows the interval centered at the cutoff point, 0.150. The observations row shows effective observations within the bandwidth. Robust standard errors are reported in parentheses. For columns 7 to 8, risk scores collected before January 2022 are included. $^{+}p < 0.1, ^{*}p < 0.05, ^{**}p < 0.01, ^{***}p < 0.001$.

Online Appendix H: Robustness to Different Samples

Table OA.6 Effects on Colonoscopy Uptake and Mortality at the Cutoff Using Different Samples

Sample	Sample including aged 50					
Outcome	Colonoscopy in 3 months		Colonoscopy in 6 months		2-year mortality	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
	(1)	(2)	(3)	(4)	(5)	(6)
Flag	0.062**	0.063**	0.073**	0.075**	-0.070*	-0.074*
	(0.019)	(0.022)	(0.023)	(0.025)	(0.028)	(0.034)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Bandwidth	[-0.069,	[-0.085,	[-0.067,	[-0.104,	[-0.086,	[-0.111,
(interval)	0.073]	0.108]	0.072]	0.140]	0.070]	0.101]
Mean below cutoff	0.030	0.029	0.060	0.053	0.136	0.117
Observations	6,088	11,037	5,788	21,387	8,696	20,700

Notes. The table presents the estimates using local linear regression (columns 1, 3, and 5) or local quadratic regression (columns 2, 4, and 6) with a triangular weighting kernel. Bandwidth shows the interval centered around the cutoff point, 0.150, using MSE optimal bandwidths (Calonico et al. 2014). The observations row shows effective observations within the bandwidth. Robust standard errors are reported in parentheses. Total observations: 64,925 (columns 1, 2, 3, and 4), 48,895 (columns 5 and 6, includes risk scores until December 2021). $^{+}p < 0.1$,$^{*}p < 0.05$,$^{**}p < 0.01$,$^{***}p < 0.001$.

Table OA.7 Effects on Colonoscopy Uptake and Mortality at the Cutoff Using One Risk Score per Patient

Sample	One risk score per patient					
Outcome	Colonoscopy in 3 months		Colonoscopy in 6 months		2-year mortality	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
	(1)	(2)	(3)	(4)	(5)	(6)
Flag	0.069**	0.073**	0.084**	0.085**	-0.067*	-0.078*
	(0.021)	(0.025)	(0.027)	(0.030)	(0.031)	(0.040)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Bandwidth	[-0.071,	[-0.085,	[-0.064,	[-0.095,	[-0.081,	[-0.099,
(interval)	0.079]	0.129]	0.077]	0.162]	0.067]	0.086]
Mean below cutoff	0.038	0.041	0.070	0.071	0.116	0.102
Observations	4,116	6,305	3,394	8,423	4,189	7,239

Notes. The table presents the estimates using local linear regression (columns 1, 3, and 5) or local quadratic regression (columns 2, 4, and 6) with a triangular weighting kernel. Control variables include age, sex, race, and insurance type (Medicare, Medicaid, military, commercial, self-pay). Bandwidth shows the interval centered around the cutoff point, 0.150, using MSE optimal bandwidths (Calonico et al. 2014). The observations row shows effective observations within the bandwidth. Robust standard errors are reported in parentheses. Total observations: 32,782 (columns 1 and 2), 24,227 (columns 5 and 6, includes risk scores until December 2021). $^{+}p < 0.1$,$^{*}p < 0.05$,$^{**}p < 0.01$,$^{***}p < 0.001$.

Online Appendix I: Analysis using Log-transformed Risk Scores

Table OA.8 Effects on Colonoscopy Uptake and Mortality at the Cutoff Using Log-transformed Risk Scores

Outcome	Colonoscopy in 3 months		Colonoscopy in 6 months		2-year mortality	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
	(1)	(2)	(3)	(4)	(5)	(6)
Flag	0.052**	0.052*	0.062**	0.067*	-0.063*	-0.070*
	(0.018)	(0.022)	(0.022)	(0.027)	(0.026)	(0.032)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Bandwidth	[-1.490,	[-1.579,	[-1.494,	[-1.296,	[-1.574,	[-2.047,
(interval)	0.432]	0.508]	0.394]	0.527]	0.361]	0.466]
Mean below cutoff	0.033	0.033	0.060	0.060	0.079	0.079
Observations	31,857	34,938	32,017	25,246	26,308	35,850

Notes. The table presents the estimates using local linear regression (columns 1, 3, and 5) or local quadratic regression (columns 2, 4, and 6) with a triangular weighting kernel. Control variables include age, sex, race, and insurance type (Medicare, Medicaid, military, commercial, self-pay). Bandwidth shows the interval of log-transformed risk score centered around the cutoff point, log(0.150), using MSE optimal bandwidths (Calonico et al. 2014). The observations row shows effective observations within the bandwidth. Robust standard errors are reported in parentheses. Total observations: 62,485 (columns 1, 2, 3, and 4); 46,994 (columns 5 and 6). $^{+}p < 0.1$,$^{*}p < 0.05$,$^{**}p < 0.01$,$^{***}p < 0.001$.

Online Appendix J: Analysis using Clustered Standard Errors

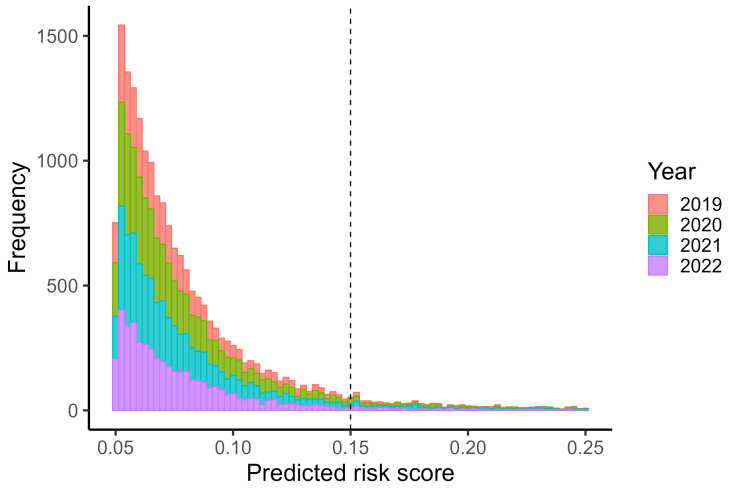
Table OA.9 Effects on Colonoscopy Uptake and Mortality at the Cutoff Using Clustered Standard Errors

Outcome	Colonoscopy in 3 months		Colonoscopy in 6 months		2-year mortality	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
	(1)	(2)	(3)	(4)	(5)	(6)
Flag	0.060**	0.059**	0.069**	0.074**	-0.062*	-0.071*
	(0.018)	(0.021)	(0.023)	(0.026)	(0.030)	(0.036)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Bandwidth	[-0.069,	[-0.086,	[-0.071,	[-0.107,	[-0.074,	[-0.097,
(interval)	0.074]	0.112]	0.077]	0.112]	0.097]	0.147]
Mean below cutoff	0.028	0.029	0.058	0.052	0.147	0.129
Observations	6,116	11,452	6,545	23,996	5,679	12,989

Notes. The table presents the estimates using local linear regression (columns 1, 3, and 5) or local quadratic regression (columns 2, 4, and 6) with a triangular weighting kernel. Control variables include age, sex, race, and insurance type (Medicare, Medicaid, military, commercial, self-pay). Bandwidth shows the interval of risk score centered around the cutoff point, log(0.150), using MSE optimal bandwidths (Calonico et al. 2014). The observations row shows effective observations within the bandwidth. Cluster (patient)-robust standard errors are reported in parentheses. Total observations: 62,485 (columns 1, 2, 3, and 4); 46,994 (columns 5 and 6). $^{+}p < 0.1$,$^{*}p < 0.05$,$^{**}p < 0.01$,$^{***}p < 0.001$.

Online Appendix K: Robustness to COVID-19 Pandemic

Figure OA.4 Density of Running Variable



(a) Distribution of risk score by year

Notes. Figure plots the distribution of predicted risk score around the cutoff by year (color), with a bin width of 0.005.

Table OA.10 Analysis with Year Effects

Outcome	With year effects					
	Colonoscopy in 3 months		Colonoscopy in 6 months		2-year mortality	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
	(1)	(2)	(3)	(4)	(5)	(6)
Flag	0.069**	0.073**	0.084**	0.085**	-0.067*	-0.078*
	(0.021)	(0.025)	(0.027)	(0.030)	(0.031)	(0.040)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Bandwidth (interval)	[-0.071, 0.079]	[-0.085, 0.129]	[-0.064, 0.077]	[-0.095, 0.162]	[-0.081, 0.067]	[-0.099, 0.086]
Mean below cutoff	0.038	0.041	0.070	0.071	0.116	0.102
Observations	4,116	6,305	3,394	8,423	4,189	7,239

Notes. The table presents the estimates using local linear regression (columns 1, 3, and 5) or local quadratic regression (columns 2, 4, and 6) with a triangular weighting kernel. Control variables include age, sex, race, insurance type (Medicare, Medicaid, military, commercial, self-pay), and year indicators. Bandwidth shows the interval centered around the cutoff point, 0.150, using MSE optimal bandwidths (Calonico et al. 2014). The observations row shows effective observations within the bandwidth. Robust standard errors are reported in parentheses. Total observations: 32,782 (columns 1 and 2), 24,227 (columns 5 and 6, includes risk scores until December 2021). $^{+}p<0.1$,$^{*}p<0.05$,$^{**}p<0.01$,$^{***}p<0.001$.

Table OA.11 Analysis with Year Effects and Excluding Deaths in 2020

Sample	Excluding deaths in 2020			
Outcome	Colonoscopy in 3 months		2-year mortality	
	Linear	Quadratic	Linear	Quadratic
	(1)	(2)	(3)	(4)
Flag	0.062**	0.061**	-0.068*	-0.075*
	(0.019)	(0.022)	(0.028)	(0.032)
Controls	Yes	Yes	Yes	Yes
Bandwidth (interval)	[-0.068, 0.069]	[-0.086, 0.105]	[-0.080, 0.055]	[-0.103, 0.102]
Mean below cutoff	0.030	0.030	0.108	0.093
Observations	5,774	11,170	6,601	15,354

Notes. The table presents the estimates using local linear regression (columns 1 and 3) or local quadratic regression (columns 2 and 4) with a triangular weighting kernel. Control variables include age, sex, race, and insurance type (Medicare, Medicaid, military, commercial, self-pay) in all columns and year dummies in columns 1 and 2. Bandwidth shows the interval centered around the cutoff point, 0.150, using MSE optimal bandwidths (Calonico et al. 2014). Robust standard errors are reported in parentheses. Total observations: 61,478 (columns 1 and 2), and 45,987 (columns 3 and 4, includes risk scores until December 2021).

Online Appendix L: Analysis of CRC Diagnosis Stages and Time to Diagnosis

In this section, we explore a potential mechanism underlying reduced mortality by analyzing the time to CRC diagnosis and the stages at diagnosis. It is important to interpret the findings here with caution, given the limited number of diagnosed cases: 59 in the control group and 23 in the treated group. Due to this small sample size, we cannot apply an RD design to estimate the treatment effect on diagnosis stages reliably. 82 observations across the risk scores are insufficient for RD analysis, which requires a larger sample to estimate the regression functions validly.

Additionally, the program's intervention (flagging and inviting patients for colonoscopy) increased colonoscopy uptake among treated group patients but not among control group patients. Consequently, control group patients are more likely to have missed CRC diagnoses. This introduces a potential selection bias when comparing diagnosis stages across groups. For example, control group patients who are not invited for a colonoscopy but are diagnosed with CRC may have more regular medical check-ups, which could influence their diagnosis stage independently of the intervention.

Considering these limitations, we compared the average diagnosis stages between groups. We collected data on CRC stages. Stages are recorded from stage 0 to stage 4 (stage 0 being the earliest stage). In the control group (n = 59), the mean diagnosis stage is 2.57, whereas in the treated group (n = 23), the mean diagnosis stage is 3.15 (t-test = 1.99, p-value = 0.053). This is an expected finding because the treated group has riskier characteristics (e.g., older), which increases the likelihood of developing CRC at more advanced stages. Although the treated group had, on average, later-stage diagnoses than the control group, they exhibited a shorter time to diagnosis from the date of risk score calculation: 211 days for the treated group versus 266 days for the control group (t-test = -0.903, p-value = 0.371).

When restricting the sample to within the MSE-optimal bandwidth around the cutoff ([-0.088, 0.112], this is the bandwidth of Table 3 column (2) in the paper), the average stages are 2.59 for the control group (n = 24), and 3.20 for the treated group (n = 13, t-test = 1.689, p-value = 0.103). The time to diagnosis within this bandwidth is 224 days for the treated group and 240 days for the control group (t-test = -0.180, p-value = 0.858). In summary, this exploratory analysis does not find strong evidence that the treated group had significantly earlier CRC diagnoses. However, the findings here should be interpreted with caution, primarily due to the limited number of diagnosed cases and the possibility that control group patients may have missed diagnoses because they were not invited for a colonoscopy by the program. Therefore, there could be more control group patients who develop later-stage CRC without being diagnosed within the sample period, or even die without a CRC diagnosis (for example, they may be diagnosed post-mortem with carcinoma of unknown primary after metastasis). We recommend that future research, with a larger sample size of diagnosed cases, rigorously examine whether earlier diagnosis serves as a mechanism for reducing mortality.

References

Calonico S, Cattaneo MD, Titiunik R (2014) Robust nonparametric confidence intervals for regression-discontinuity designs. *Econometrica* 82(6):2295–2326.

McCrary J (2008) Manipulation of the running variable in the regression discontinuity design: A density test. *Journal of Econometrics* 142(2):698–714.