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Original Article

Colorectal Cancer Screening Programs: The Causal Effect of Their Organization and Testing Strategy on Participation

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Abstract

Background: Early detection of colorectal cancer (CRC) greatly increases the chances of cure, but participation in CRC screening programs remains low. The degree of organization and the testing method of these programs are key determinants of participation, yet causal evidence on how these program characteristics affect take-up remains scarce. Austria offers a unique setting to address this gap, with three co-existing CRC screening programs varying in organization and testing strategy across provinces. This paper estimates the causal effect of these three programs on screening participation to identify which program characteristics are most effective at increasing take-up.

Methods: We exploit regional and age-based variation in program eligibility, using claims data from a large Austrian public health insurer, and apply difference-in-differences (DD) and regression discontinuity (RD) methods to identify the programs' causal effects.

Results: All three screening programs increase participation. The effect is strongest for the population-based program, which has the highest degree of organization and includes regular mailings of stool test kits. Participation in stool test-based screening increases by 30 percentage points (pp) on average among those aged 40 to 80 (DD) and by 20 pp at the age-40 eligibility cutoff (RD). The medium-organized program, which includes a quality assurance system and a guarantee of a qualified workforce, but offers colonoscopies without an invitation system, increases colonoscopy take-up by 0.8 pp on average (DD) and 1.2 pp at age 50 (RD). The low-organized program, where screening is offered within the annual general practitioner (GP) health checkup, increases participation by 12 pp for stool tests, and 0.5 pp for colonoscopies at age 50 (RD). Participation increases further when two programs co-exist.

Conclusion: Screening participation increases with the degree of organization of the screening program. Combining various program types could be beneficial in reaching larger shares of the target population.

Keywords: Colorectal Cancer Screening, Organized Screening Program, Population-Based Screening, Screening Participation, Screening Tests, Austria

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Background

Colorectal cancer (CRC) is among the most prevalent cancers worldwide; its incidence has been growing in the past decades, and the age at first diagnosis is decreasing. CRC is the second leading cause of cancer-related death after lung cancer.[1] On the positive side, the chance of survival increases when detected early.[2-4] Extensive screening among the at-risk population reduces both individual risks and costs for the health system due to CRC.[5-7] However, the uptake of regular cancer screening is relatively low, ranging from an estimated 20% to 50% across most OECD (Organisation for Economic Co-operation and Development) countries[8,9] which limits the overall impact of screening. Introducing effective strategies that aim to increase screening participation is therefore key.

Common structural barriers to screening include cost and access constraints, such as affordability, travel distance to screening facilities, or limited appointment availability. These barriers explain part of the low uptake in screening and have been shown to drive socioeconomic inequalities in cancer screening participation.[10] Uptake of cancer screening is also shaped by behavioral and psychological barriers, including low perceived risk in the absence of symptoms, limited awareness of the benefits of screening, fear of a positive diagnosis, and the absence of a physician recommendation. CRC screening also faces specific barriers that help explain why participation lags behind screening for other cancers, even when screening is free and access is guaranteed.[11,12] Commonly cited examples include embarrassment or disgust associated with stool-based testing and fear of the procedure itself, particularly for colonoscopy.[11-14]

Screening programs differ in the extent to which they are designed to address these barriers, reflected in both their degree of organization and the specific screening method that is used. Regarding the former, the definition of an Organized Screening Program (OSP) has recently been updated to reflect current variations in screening organization.[15,16] The

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Key Messages

Implications for policy makers

- The results of this paper are relevant to policy-makers when considering different screening tools, screening frequency, and organizational structures for their colorectal cancer (CRC) screening programs.
- Screening participation is the highest within the population-based screening program, which includes a personal invitation and a stool test kit sent at home.
- When colonoscopy is chosen as screening tool, guaranteeing a qualified workforce combined with quality assurance doubles participation.
- The impact of the screening programs is increasing with age from 40 to 70 years.
- Combining different screening programs could reach larger shares of the target population.

Implications for the public

Regular cancer screening is important as early detection increases the chances of cure substantially. Different screening programs exist that vary in their degree of organization and testing strategy. All these programs offer screening free of charge. The population-based program characterized by the highest degree of organization, including an information leaflet and the regular sending of a stool test kit at home, has the largest effect on participation. When colonoscopy is the screening tool of choice, guaranteeing a qualified workforce matters and doubles screening participation. Offering various ways to screen (stool test or colonoscopy) at the general practitioner's (GP's) office and mailing the stool test kit directly to people's homes increases participation.

degree of organization is assessed across five building blocks: governance, a qualified health workforce, access to services, service delivery provisions, and an information system with quality assurance. A population-based program corresponds to the highest degree of OSP, as it includes essential components relating to service provisions: the definition and identification of the target population, free access to screening, an invitation system of the eligible population, and a notification and information system about the test results managed by a central authority (eg, health insurance providers or public health authorities).[15] Lower degrees of organization include only some of these criteria.[16]

With respect to the screening method, two main testing tools are available to detect CRC. The least invasive screening method, which is also less precise, is a stool test that checks for hidden blood as an indicator of CRC.[4,10,17] Positive stool tests usually need to be confirmed by a subsequent colonoscopy. Alternatively, colonoscopies can also be used as a primary screening method. While the advantage of a colonoscopy is its precision, the disadvantages include a higher degree of invasiveness, a higher risk of adverse side effects, and higher costs.[4,18]

The variations in the design of screening programs across the Austrian provinces provide an opportunity to address four main research questions. First, how does the degree of organization of a CRC screening program affect screening participation? Second, does offering a mailed stool test as first screening tool versus relying on colonoscopy only affect participation differently? Third, does extending eligibility to a younger population (age 40 rather than age 50) have an impact on participation? Fourth, how does the co-existence of two CRC screening programs impact screening participation?

More specifically, we compare three different degrees of organization of programs: (1) A "low-organized" program in which CRC screening is included in the General Health Screening Program (GHSP) annually from the age of 50. Both a stool test and a colonoscopy are available as initial screening tools throughout the country. (2) A "medium-organized" program that additionally offers quality assurance and guarantees the qualification of the workforce for colonoscopies, but that does not include an invitation system for screening. These colonoscopies are offered as initial screening tool from age 50 as part of a program implemented in the Vorarlberg province. (3) A "high-organized" program or population-based program in place in the Burgenland province in which the eligible population (aged 40-80) additionally receives a stool test kit in the post as initial screening tool.

Our study contributes to the evidence of the literature on the impact of CRC screening programs on participation in the following ways.

Our paper relates to the previous studies that identify the causal effects of cancer screening on participation using quasi-experimental methods. Our difference-in-differences (DD) design nets out time-invariant regional and age-related confounders, while our regression discontinuity (RD) design compares individuals just above and below an age-eligibility threshold in a local randomization setting. These methods address the selection bias that limits the observational literature, while capturing real-life, population-wide responses that RCTs usually cannot.[19] Thanks to data from the largest public health insurance provider in Austria, we are able to measure these impacts precisely. To the best of our knowledge previous evidence from RCTs focused on measuring the effects of specific behavioral features on participation within existing CRC screening pathways such as conditional financial incentives, reminder letters or comparing different test-invitation modalities and found that these interventions produce statistically significant increases in screening uptake.[20-24]

Our paper adds to the previous evidence on similar OSPs for cancer implemented in Europe. Most of the papers focused on the impact of OSPs for breast cancer on mammography uptake. These papers found a large effect of OSPs on screening participation of around 25–30 percentage points (pp).[25-30] Evidence on OSPs for CRC in Europe is scarcer.[31,32] On average, the impact of OSPs on screening for CRC using stool tests in the European Union is around 20 pp.[32]

These studies have focused on the impact and spillover effects of one type of OSP, namely the impact of a population-based program, which is currently the program with the

highest degree of organization in European countries. Thanks to the current Austrian CRC screening strategies, we can study screening participation under different organizational degrees as well as when both screening tools (stool test and colonoscopy) are offered as first screening tools.

Our study differs from the evidence on cancer screening in the US. The impact measured in US-based studies is the impact of having (free) access to screening through health insurance coverage.[33] In Europe usually, and specifically in Austria, CRC screening is offered free of charge also for individuals outside of the eligibility age ranges (opportunistic screening). What we measure in our paper is therefore the impact of information provision (via sending letters or at the general practitioner [GP] office) and the impact of quality assurance for colonoscopy. Our study relates to the evidence in Canada. Blair et al[34] found that the systematic mailing of stool tests at home increases screening uptake and reduces screening inequalities relative to a patient-reliant program in which individuals self-request the stool test at the GP office.

Finally, we can contribute to the current debate on whether the age of eligibility for screening should be lowered in light of the observed increased cancer incidence in the younger population[35-37] by measuring age-specific effects on screening participation of the population-based program starting at age 40, when the majority of the evidence comes from programs in Europe starting at age 50.

This study is of particular relevance for Austria, because CRC is the third most commonly diagnosed cancer and one of the leading causes of cancer death, with 4769 new diagnoses and 2073 deaths recorded in 2024,[38] together accounting for around 10% of all incident cancers and 10% of all cancer deaths in the country.[39] Despite the significant disease burden, participation in the country's longest-running screening program, the GHSP, remains low. Each year, around 16% of the population aged 50 and above participate in the GHSP.[40] This figure is well below that achieved in countries with more organized, invitation-based programs, and falls short of the European Commission's recommended target participation rate of at least 65%.[41] The combination of a high disease burden and low screening uptake for CRC emphasizes the importance of identifying the most effective program features for increasing participation. Our findings are therefore relevant not only for Austria but also for other countries with comparable CRC screening strategies.

Methods

Study Setting

Cancer screening programs aim to reach the asymptomatic population at risk of developing cancer. In Austria, three different screening programs are currently established, varying in their degree of organization. Below, we describe each program.

Screening for CRC is included in the GHSP conducted at GP practices.[42] All insurees aged 50 or older in Austria have access to a stool test every year. Furthermore, insurees in this age group can make an appointment for a colonoscopy every 10 years. Participation in the GHSP is voluntary and examinations within the program are fully covered. However, there is no invitation system, no specific Austrian-wide quality certificate, and no mandatory quality control for colonoscopies.[40,43,44] We classify this program as low-organized compared to the two other programs available in Austria.

In the Vorarlberg province, the Vorarlberg Screening Program (VSP) was established in 2007 to introduce quality standards for screening colonoscopies in line with international recommendations. These quality standards cover (*i*) counselling and information provision before the colonoscopy, (*ii*) the procedure itself, namely the use of premedication or sedation, aftercare, hygiene, the diagnostic, and the reporting of findings, and (*iii*) the provision of colonoscopies, covering the qualification of the specialists and the technical requirements of the service providers.[45] Insured persons aged 50 or older in Vorarlberg are eligible for a colonoscopy examination that includes these quality standards every ten years. The VSP corresponds to the medium-organized program in our study.

In 2003, the province of Burgenland started to roll out a yearly population-based screening program for CRC, the Burgenland Screening Program (BSP), which covers the whole province from 2006 onward. Everyone residing in Burgenland aged between 40 and 80 is eligible for the program. The target population receives an information letter, and a stool test kit mailed to their home address. Participants collect their stool sample at home and return the test kit either to their GP or to a local collection point. Those who screen positive for occult blood get invited to a follow-up colonoscopy.[40,43] The BSP corresponds to the high-organized program in our study.

All costs associated with screening under the three programs are fully covered, including the initial consultation, laboratory analyses, and any follow-up examinations or procedures prompted by a positive test result. Opportunistic CRC screening (ie, screening outside of these programs) is also possible on physician recommendation. This is particularly relevant for insurees who are not yet eligible due to age or who have already undergone a colonoscopy within the mandatory ten-year interval under the VSP or GHSP. This opportunistic screening is relatively common, accounting for a quarter of all CRC screenings in our claims data, and is likewise fully reimbursed when conducted by a physician covered by public health insurance.

Data Sources and Study Sample

We use individual-level data on healthcare utilization from Austria's largest social health insurance provider, which covers the majority of privately employed individuals, their dependents, retirees, and the unemployed.[46,47] Therefore, the estimated program impacts provide a good approximation for the effects on the total population.

The cross-sectional sample includes individuals aged 30 to 90 years old in 2022, in other words, it includes individuals who are at most 10 years younger or older than the BSP's eligibility age range (40-80 years old). To construct the sample, we merge individual-level claims data (N = 4 339 850) with disaggregated data on the number of insurees at the province-age-sex level (N = 5 106 309), to ensure that insurees with no healthcare utilization in 2022 are included. Since the province

of residence is central to treatment assignment, we exclude insurees without residence information or outside the age range of interest from the disaggregated data (N = 240 810), as well as those with incomplete province or sex information or aged above 90 from the claims data (N = 128 751). This results in a final sample of N = 4 865 506 insurees.

The information available in the claims data and the sample construction process are described in more detail in Supplementary file 1.

Definition of Screening Variables and Descriptive Statistics

We measure CRC screening participation in 2022 using two variables; (*i*) a binary variable indicating whether each insuree undertook a stool test, and (*ii*) a binary variable indicating whether each insuree underwent a colonoscopy as their first screening method.

Table 1 provides summary statistics of the two screening variables, both overall and for Burgenland, Vorarlberg, and the other Austrian provinces separately. Overall, 12.5% of the sample participated in CRC screening; 10.4% via a stool test and 2.1% via a colonoscopy as first screening tool. The screening rate by stool test is much larger in Burgenland (34.5%) compared to Austria overall (10.4%). The proportion of colonoscopy use as first screening tool is lower in Burgenland (1.3%) than in the rest of Austria (2.1%). As can be seen in Table 1, the average number of GP visits is 9.8. This figure is slightly higher in Burgenland (12) and lower in Vorarlberg (7.5). The mean age is 54.3, with 52.8% of the sample being female.

Figure 1 shows CRC screening participation by age separately for Burgenland, Vorarlberg, and the other Austrian provinces. In Burgenland, screening participation in stool testing is much higher than in Vorarlberg and the other Austrian provinces, particularly among those aged 40-80 who are targeted by the screening program in Burgenland. In Vorarlberg, participation in stool testing is similar to that in the other Austrian provinces where screening is offered only via the GHSP. Figure 1 shows that once eligibility starts at age 50, participation in colonoscopy screening is higher in Vorarlberg than in Burgenland, and in the other Austrian provinces. This suggests a positive effect of the VSP offering quality standards for colonoscopies. Figure 1 further shows that increases and decreases in CRC screening occur at the various program age thresholds.

Analytical Approach

To provide plausible causal estimates of the impact of the BSP and the VSP on screening participation, we exploit variations in program eligibility by province and age in a DD set-up, in which age plays the role of time, similar to other identification strategies that estimate the effect of organized programs on cancer screening participation.[25,30,32]

Specifically, we estimate the following model:

$$Screen_{ip} = \alpha + \beta BSP_{ip} + \lambda_a + \kappa_p + \gamma x_{ip} + \varepsilon_{ip} \quad (1)$$

where $Screen_{ip}$ is an indicator for whether insuree i living in province p screened for CRC, $BSP_{ip} = 1$ if province p is Burgenland and insuree i's age makes him/her eligible for the BSP, λ_a are age fixed effects, and κ_p are province fixed effects. x_{ip} is a vector of insuree-level controls (female and the number of GP visits as a proxy for health status). Scalars α and β and vector γ are parameters to be estimated and scalar ε_{ip} is the error term. For the evaluation of the VSP, the *BSP* variable is substituted by the *VSP* eligibility variable. We cluster standard errors at the *age* × *province* level, where treatment is applied.[48]

With equation 1, we can estimate (*i*) the causal effect of the BSP relative to the GHSP by excluding insurees living in the Vorarlberg province, and (*ii*) the causal effect of the VSP compared to the GHSP by excluding insurees living in the Burgenland province. Under the parallel trend assumption on the effect of the GHSP in Burgenland (Vorarlberg) in absence of the province-specific program, the DD setup allows us to cancel out the effect of the GHSP in Burgenland (Vorarlberg) and identify the incremental effect of the BSP (VSP), respectively. The effects of both programs are estimated on the probability of undergoing screening with a stool test or a colonoscopy as the first testing tool using a two-way fixed effect linear probability model.

Since the various age thresholds introduce discontinuities in treatment assignment (ie, eligibility for the screening programs), and insurees cannot manipulate the running variable used for treatment assignment, we can also apply RD methods to estimate the local treatment effects of the different screening programs on CRC screening participation. The eligibility conditions in terms of age and province create the following four groups in terms of access to CRC screening programs: (*i*) no screening program (below age 40 in Burgenland, and below age 50 in Vorarlberg and the other Austrian provinces, (*ii*) access to only the BSP (ages 40-49 in

Table 1. Summary Statistics

	Overall	Burgenland	Vorarlberg	Other Austrian Provinces
Outcome variables				
Stool test screening	10.4%	34.5%	10.3%	9.5%
Colonoscopy screening	2.1%	1.3%	2.1%	2.1%
Control variables				
Age	54.3 (15.5)	56.5 (15.2)	54.7 (15.6)	54.2 (15.5)
Female	52.8%	53.9%	53.4%	52.7%
No. of GP visits	9.8 (11.4)	12.0 (11.8)	7.5 (9.1)	9.8 (11.5)
No. Observations	4 865 506	159 760	216 652	4 489 094

Abbreviation: GP, general practitioner.

Note: Summary statistics by treatment group for 2022. Screening participation rates reflect first screening choice.

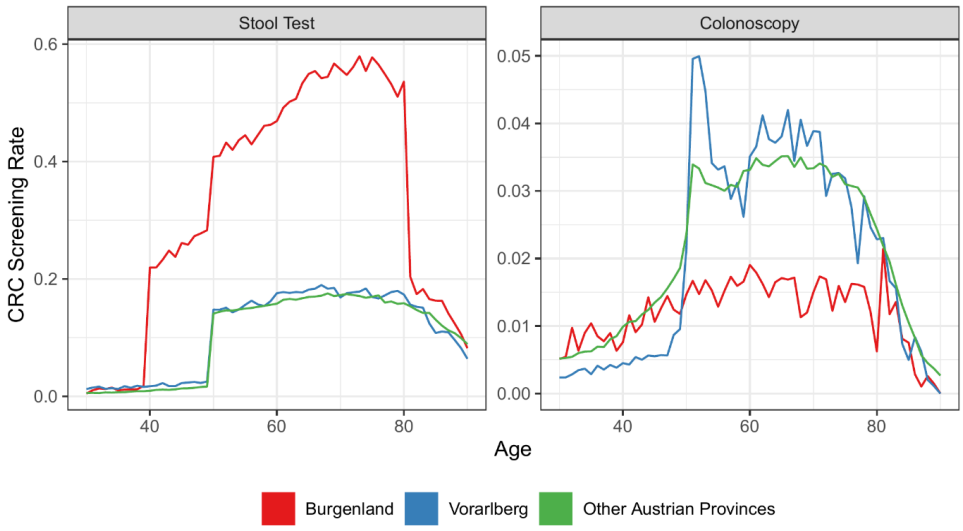


Figure 1. Participation in Colorectal Cancer Screening. *Note:* The figure shows the shares of insurees aged 30 to 90 who participated in CRC screening in 2022, broken down by the first screening method. Abbreviation: CRC, colorectal cancer.

Burgenland), (*iii*) access to only the GHSP (ages 50+ in the other Austrian provinces), and ages 81+ in Burgenland), and (*iv*) access to both the GHSP and VSP (ages 50+ in Vorarlberg).

This allows us to measure several causal effects and address the following research questions at the RD cutoffs:

- Age 40:
  - Burgenland: How does access to the BSP affect CRC screening participation in the absence of any screening program?
- Age 50:
  - Burgenland: How does having access to the GHSP in addition to the BSP affect CRC screening?
  - Vorarlberg: How does access to both the VSP and GHSP affect CRC screening participation compared to no access to any screening program?
  - Other Austrian provinces: How does access to the GHSP affect participation in CRC screening compared to no access to any screening program?
- Age 81:
  - Burgenland: How does losing access to the BSP affect participation in CRC screening while retaining access to the GHSP?

Supplementary file 2 describes in full detail the regression models and identification strategy for the DD estimates and the RD estimates.

We also investigate potential heterogeneity in program effects. In the DD setting, we interact the program eligibility indicator with the age fixed effects to obtain age-specific treatment effects. We further interact the program eligibility indicator with the indicator variable for women to study heterogeneity in the effects by sex. As with the DD estimates, we analyze effect heterogeneities by sex for our RD estimates. Here, we fully interact our baseline local randomization RD models which allows us to test for significant differences in treatment effects by sex, producing estimates equivalent to a subsample analysis.

Sensitivity Analysis

To provide additional support for a causal interpretation of the effects, we run a number of validation and falsification tests.

First, we address the issue that our measurement of participation in the GHSP relies on birth dates, which are only available to us in birth years. This likely leads to wrongly assuming screening participation for some insurees at the program threshold (age 50), ie, for those who underwent the voluntary health check-up in the year they turned 50 while they were still 49. To determine the extent to which our results are influenced by this issue, we estimate the baseline DD and RD models excluding insurees aged 50 (N = 99 051). Another factor that could misallocate treatment group status is inter-province migration: individuals who moved between provinces during the observation period may be misclassified with respect to their screening program exposure, which could attenuate our treatment effect estimates. To account for this, we re-run our baseline models excluding insurees who moved between provinces within the year (N = 30 146). We identify inter-province migration as cases where insurees reported at least two different provinces of residence when utilizing healthcare within a year.

The age-specific treatment effects in the DD analysis provide further insight into the plausibility of the parallel trend assumption by examining pre-treatment effects. Furthermore, we conduct a leave-one-out robustness check in both the DD and RD analyses to test the sensitivity of our results to the choice of control group. In the RD analysis, we estimate effects at placebo cutoffs and check the sensitivity of our estimates to the choice of window around the cutoff. Additionally, we provide estimates for the full sample RD effects using parametric RD estimation as an alternative to our local randomization approach.

During the COVID-19 pandemic, access to and use of preventive healthcare and, especially, cancer screening decreased significantly.[49,50] This could still affect screening participation in 2022. To account for this possibility, we test

the robustness of our main results using pre-pandemic data from 2019.

Results

Difference-in-Differences Estimates

Table 2 reports the DD estimates. The BSP increases screening participation in stool testing by 29.9 pp, while participation in colonoscopies decreases by 1.3 pp. This reflects a shift from using colonoscopies as the first screening method to using stool tests. The impact of the VSP on stool tests is not statistically different from zero; however, it increases participation in colonoscopies by 0.8 pp.

Figure S2 in Supplementary file 3 shows the effects by age of the BSP (40-80) and VSP (≥50) compared to the GHSP in the other Austrian provinces. The impact of the BSP on stool tests increases with age, from 20 pp at age 40 to close to 40 pp at age 70. The impact of the VSP on colonoscopies is the highest at age 50 (when eligibility begins), exceeding 2.5 pp, and declines with age, reaching 1 pp at age 90. Table S2 and Figure S3 report the results of the heterogeneity analysis by sex. The impact of the BSP on stool tests is larger for women than for men. However, the impact of the VSP on colonoscopies does not differ significantly by sex.

Regression Discontinuity Estimates

Figure 2 depicts the discontinuities in CRC screening participation at the different cutoff ages in Burgenland, Vorarlberg, and the other Austrian provinces. The graphical analysis shows that screening participation in stool testing increases sharply at each program start age threshold; in Burgenland (ages 40 and 50, Figure 2 panel (a)), in Vorarlberg and in the other Austrian provinces (age 50; Figure 2 panel (b) and panel (c)). In Burgenland, participation rates for stool tests decrease sharply after age 80 (Figure 2 panel (a)) when insurees lose eligibility for the BSP.

Similarly, participation in colonoscopies increases sharply at the age of 50 in Vorarlberg and in the other Austrian provinces (Figure 2, panel (b) and panel (c)) when the VSP and the GHSP start. In Burgenland, where the BSP and GHSP co-exist, the discontinuity in colonoscopy participation at age 50 is less clear.

Table 3 reports estimates of the local average treatment effect (LATE) within the smallest windows around the cutoffs at age 40 (the start of BSP eligibility), 50 (the start of both VSP and GHSP eligibility), and 81 (the end of BSP eligibility, while eligibility for the GHSP and VSP continues).

Compared to having no access to any screening programs, eligibility for the GHSP at age 50 increases stool test screening by 12.4 pp (more than sevenfold relative to the mean participation at age 49) and colonoscopy screening by 0.5 pp (a 26% increase relative to the mean participation at age 49). In the first year of eligibility for the program, when both screening tests are available, a stool test is used far more often than a colonoscopy as the initial screening tool (cutoff at age 50, panel 3(c)).

The BSP increases participation in stool testing by 20.2 pp compared to having no access to other screening programs. This is more than a elevenfold increase relative to the mean participation at age 39 (cutoff at age 40, panel 3(a)). When individuals in Burgenland become eligible for the GHSP at age 50, participation in stool testing increases by 12.5 pp compared to access to only the BSP. The coexistence of the two programs in Burgenland appears to have a positive effect on participation; eligibility for the GHSP further increases participation in stool testing by 44% relative to eligibility for the BSP only at age 49 (cutoff at age 50, Panel 3(a)). Conversely, when individuals lose access to the BSP at age 81, participation decreases by 33.3 pp in Burgenland, corresponding to a decrease of over 60% relative to the mean participation rate for 80-year-olds in Burgenland (cutoff at age 81, Panel 3(a)).

In Vorarlberg, both the GHSP and the VSP start at age 50. We find no effect on screening participation at the age 40 placebo cutoff (cutoff at age 40, panel 3(b)). At age 50, participation in screening increases by 12.3 pp compared to having access to no screening program at age 49 (an almost fivefold increase relative to the mean participation rate at age 49) for stool tests. This increase in stool tests is similar in magnitude compared to the increase observed for the GHSP in the control provinces. In Vorarlberg, eligibility for both the GHSP and the VSP increases colonoscopy screening by 1.2 pp (a 120% increase relative to the mean participation rate at age

Table 2. Effects of Burgenland and Vorarlberg Screening Programs on Screening Uptake, Difference-in-Differences Estimates

	DV: Stool Test		DV: Colonoscopy	
	BSP	VSP	BSP	VSP
BSP eligibility	0.299***		-0.013***	
	(0.010)		(0.001)	
VSP eligibility		0.002		0.008***
		(0.003)		(0.001)
Controls	X	X	X	X
Province FE	X	X	X	X
Age FE	X	X	X	X
Observations	4 648 854	4 705 746	4 648 854	4 705 746

Abbreviations: DV, dependent variable; BSP, Burgenland Screening Program; VSP, Vorarlberg Screening Program; FE, fixed effects; X, included in model.
Note: Estimates for the effects of eligibility for the BSP and the VSP from DD models. The treatment groups include Burgenland (for BSP) and Vorarlberg (for VSP) residents, respectively. The control group includes residents of the other seven provinces. Individual-level controls include sex and the number of GP visits. Clustered standard errors at the province x age level in parentheses. Significance: *** $P < .001$, ** $P < .01$, * $P < .05$.

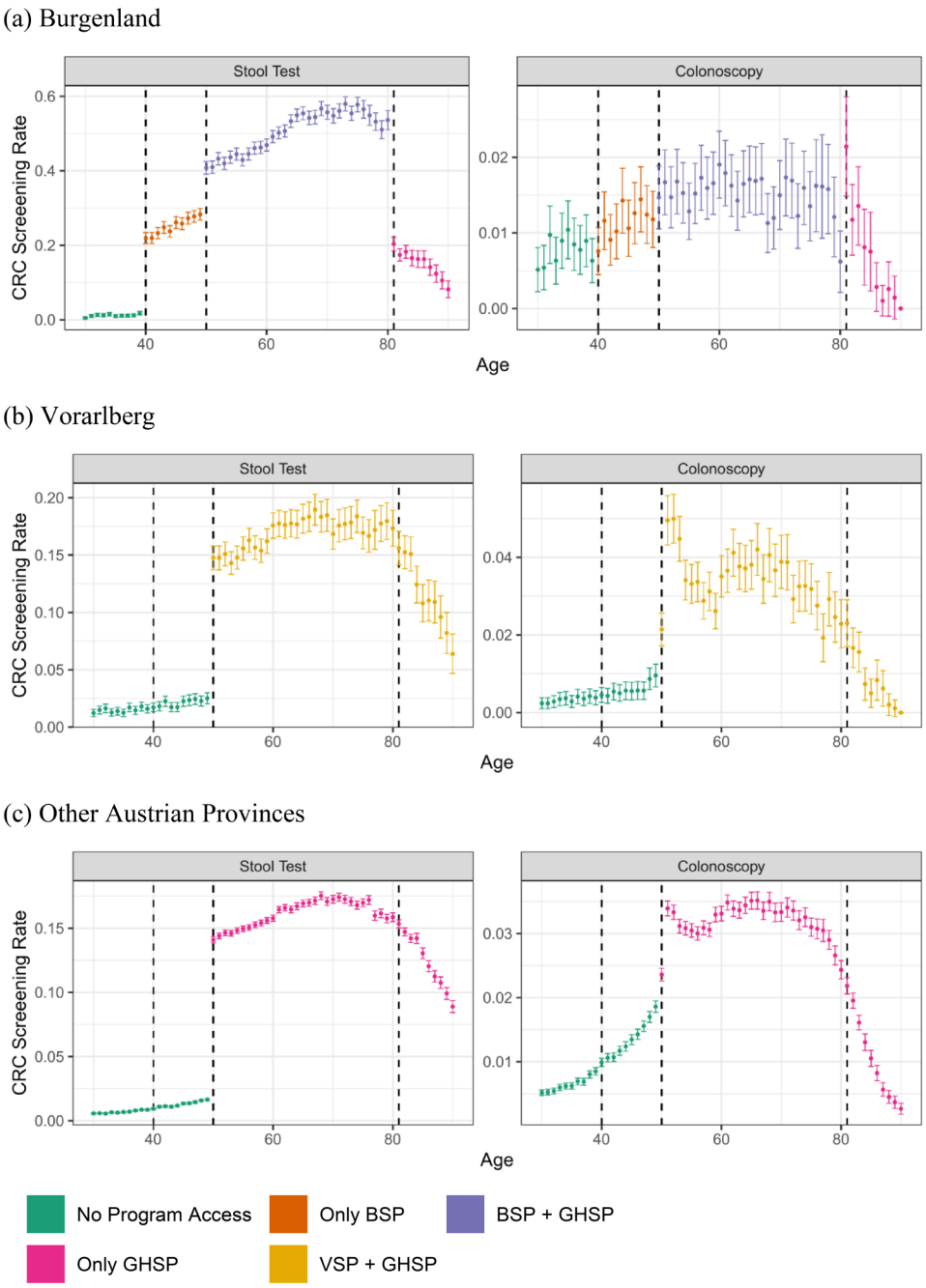


Figure 2. Regression Discontinuity Plots of Screening Participation. *Note:* RD plots show binned CRC screening rates (=share of sample population screening for CRC) with 95% CIs for each age cohort in 2022 for stool test (left) and colonoscopy (right). Panel (a) shows the RD plot for Burgenland, panel (b) for Vorarlberg, and panel (c) for other Austrian provinces. Abbreviations: BSP, Burgenland Screening Program; VSP, Vorarlberg Screening Program; GHSP, General Health Screening Program; CRC, colorectal cancer.

49, cutoff at age 50, panel 3(b)). The increase in colonoscopies is larger when both the GHSP and the VSP are available than when only the GHSP is available (cutoff at age 50, panels 3(b) and 3(c)).

Tables S6-S8 in Supplementary file 4 report the impacts of the three screening programs by sex. While women tend to screen slightly more than men at the lower age cutoffs, we find no significant differences in the impact of screening programs by sex for almost all cutoffs. The only exception is access to the GHSP only, where women in other Austrian provinces are more likely to undergo stool testing at age 50 (See Table S8). We find no significant differences by sex for colonoscopy screening.

Sensitivity Analysis

Figures S4 and S5 in Supplementary file 3 report the results of the leave-one-out analysis, which show that our DD estimates are robust to excluding insurees from any given Austrian province within the control group. DD results are also not driven by the measurement of age based on birth year alone, as excluding the potentially problematic group of 50-year-old insurees does not significantly influence the estimates (See

Table 3. Local Effects on Screening Participation at Age Eligibility Cutoffs, Regression Discontinuity Estimates

			DV: Stool Test		DV: Colonoscopy	
Cutoff	**W**	**N**	**LATE [95% CI]**	**Mean [Age < c]**	**LATE [95% CI]**	**Mean [Age < c]**
			(a) Burgenland			
40	[39, 40]	2842 | 3027	0.202***	0.018	0.001	0.006
			[0.186, 0.217]		[-0.003, 0.006]	
50	[49, 50]	3223 | 3201	0.125***	0.283	0.003	0.012
			[0.102, 0.148]		[-0.003, 0.008]	
81	[80, 81]	1449 | 1866	-0.333***	0.536	0.015***	0.006
			[-0.364, -0.301]		[0.008, 0.023]	
			(b) Vorarlberg			
40	[39, 40]	4438 | 4662	0.001	0.016	0.001	0.004
			[-0.004, 0.006]		[-0.002, 0.003]	
50	[49, 50]	4294 | 4483	0.123***	0.025	0.012***	0.010
			[0.111, 0.134]		[0.007, 0.017]	
81	[80, 81]	2233 | 2389	-0.017	0.173	0.000	0.023
			[-0.039, 0.004]		[-0.008, 0.009]	
			(c) Other Austrian Provinces			
40	[39, 40]	94 710 | 96 022	0.001	0.009	0.001**	0.008
			[0.000, 0.002]		[0.001, 0.002]	
50	[49, 50]	87 150 | 91 367	0.124***	0.017	0.005***	0.019
			[0.122, 0.127]		[0.004, 0.006]	
81	[80, 81]	44 710 | 49 684	-0.005*	0.159	-0.002*	0.024
			[-0.010, -0.001]		[-0.004, -0.001]	

Abbreviations: DV, dependent variable; LATE, local average treatment effect; CI, confidence interval.
Note: Estimates for local treatment effects on screening participation, using local randomization RD. Panels (a), (b), and (c) show results for residents of Burgenland, Vorarlberg, and other Austrian provinces; respectively. Point estimators report difference-in-means, *P* values, and CIs are based on large-sample approximations. Significance: *** $P < .001$, ** $P < .01$, * $P < .05$.

Table S3 and Figure S6). Our effects are also robust when insurees who migrated between provinces within the year are excluded (See Table S4 and Figure S7). Furthermore, the results can be replicated using data from 2019 instead of 2022, both qualitatively and quantitatively, as Table S5 and Figure S8 show.

Figure S9 in Supplementary file 4 reports the results of the leave-one-out analysis for the RD estimates. As with the DD estimates, the RD estimates for the other Austrian provinces are robust to excluding insurees from any given control province.

To validate the assumptions of the RD design, we conduct several falsification tests. First, we consider the local treatment effects at placebo cutoffs. If the local randomization assumptions hold, we would expect to see no effect in small windows around the artificial cutoffs that only include units below (or above) the true cutoff. This is because only the program access itself should lead to a discontinuity in screening participation. We consider two placebo cutoffs, one directly below the true cutoff (W− = [c−2, c−1]) and one directly above (W+ = [c, c+1]). Figure S10 in Supplementary file 4 shows the results of this robustness check for the three groups of provinces. For Burgenland, the differences at the placebo cutoffs are mostly insignificant, except for the placebo cutoffs at age 81, where a negative and significant effect is also present at the upper placebo cutoff. However, its magnitude is only a fraction of the effect measured at the real cutoff point of 81. This suggests that, while screening participation appears to decline even after eligibility for the BSP ends, a large share of the effect at the age 81 cutoff is still due to the end of the program eligibility and not simply to a general decline due to advanced age. In Vorarlberg, the impacts at the placebo below-cutoffs are not statistically different from zero. For colonoscopies, the placebo above-cutoff at age 50 is positive and significant reflecting an increase in colonoscopy participation with age when insurees are eligible for both the VSP and the GHSP. A similar positive effect is observed in the other Austrian provinces.

We also check the sensitivity to the window choice. Note, however, that under the local randomization approach, the local randomization assumptions are less likely to be met in windows of increasing size. Therefore, the resulting estimates should only be interpreted with caution. Results are reported in Tables S9-S11. For colonoscopies, we find that treatment effects in Vorarlberg at age 50 (the start of eligibility for colonoscopies via screening programs) increase notably when the window is increased from one year above and below the cutoff to two years, but remain stable with further increases. This might indicate that screening programs offering colonoscopies take longer to achieve the full program effect magnitude, eg, due to the time taken to arrange appointments. We find a similar pattern in control provinces, but not in Burgenland.

Table S12 additionally shows that excluding the potentially problematic age group of 50-year-old insurees does not drastically impact the local effects at the relevant cutoff for

stool test screening participation. However, for colonoscopies, the effects in Vorarlberg and the other Austrian provinces are about three times as large. Table S13 indicates that our RD results are not driven by migrants between provinces.

Furthermore, we parametrically estimate the effects at the age cutoffs instead of following our preferred local randomization approach. Table S14 in Supplementary file 4 shows that effect sizes are qualitatively and quantitatively comparable. Finally, as Table S15 shows, the main results from the RD analysis can be replicated using 2019 data instead of 2022 data, both qualitatively and quantitatively.

Discussion

We study the impact of three different programs aimed at increasing screening participation for CRC. We use regional and age eligibility variations in the screening programs to identify the causal effects of the programs, and employ DD and regression discontinuities using claims data from the largest public health insurance provider in Austria.

All three screening programs increase participation. The effect is strongest for the population-based screening program, which is characterized by the highest degree of organization, and includes the regular mailing of stool test kits. Participation increases by 30 pp on average among those aged 40 to 80 and by 20 pp at the youngest age cutoff of 40. These findings are in line with previous studies measuring the causal effect of organized cancer screening programs or population-based screening, including an invitation system, on participation.[25-32,34] Regarding the impact of CRC screening with stool testing specifically, our participation estimates are similar to those found in other countries with estimates ranging from around 20 to 40 pp.[8,31,32,34]

The age-specific effects show that the impact of the population-based screening program increases with age from ages 40 to approximately 70. These estimates are relevant to the current policy debate on the choice of the age range targeted by CRC screening programs.[35-37]

This increase in participation with age is associated with the number of invitations received over time. Within the BSP, letters are sent annually. In our study, we are unable to distinguish the effect of age from the number of invitations received over time. However, previous studies have found that the number of letters received over time matters and increases participation at a given age.[30,32] Therefore, part of the sharp increase in participation with age may be driven by the number of previous letters received. This finding reinforces the importance of an invitation system for increasing participation. Additionally, since all screening programs are free, our results suggest that reducing barriers to screening through direct invitations and at-home testing in the BSP is a major driver of the effect size of the population-based screening program.

The impact of the low-organized program in which CRC screening is offered as part of the GHSP is 12 pp at age 50 for stool tests and 0.5 pp for colonoscopies. Joint access to the low-organized program and to the medium-organized program, which includes a quality assurance system and a guarantee of a qualified workforce, but that only offers colonoscopies without an invitation system, increases the screening take-up by 1.2 pp. Although this increase may seem small at first glance, it is roughly twice the magnitude of the impact of access to the low-organized program alone. This effect is driven solely by the guarantee of quality assurance based on detailed guidelines and information provision at the GP office. The program was introduced to address the psychological costs associated with a more invasive screening method and to lower the risk of adverse side effects from a more precise test that needs to be repeated far less frequently (once every ten years).[4,11-13,18]

We show that combining two program types can further increase participation, as access to the GHSP also had a positive effect among those insurees who already had access to the high-organized program in Burgenland. The two programs, the BSP (a stool test sent via mail with an information leaflet) and the GHSP (a stool test performed at the GP's office during the annual checkup), appear to complement each other. The BSP reaches individuals who would not otherwise be screened by the GHSP until age 50. Several potential mechanisms could explain this result. Information sent via the BSP mailing appears to raise awareness, which develops over time and transforms into actual uptake when individuals also have access to the GHSP during their annual checkup from age 50, acting as a "cue to action."[51-54] Alternatively, the GP visit may simply be a more persuasive channel than a mailed letter. This is consistent with evidence showing that personalized provider communication strongly predicts screening adherence[55,56] and produces a catch-up effect among those who have postponed screening.

Furthermore, it seems that the BSP screens a large proportion of individuals under 50 with a stool test, some of whom would have undergone a colonoscopy at age 50. In Burgenland, the RD point estimate of the BSP + the GHSP at age 50 for colonoscopies is smaller and not statistically significant, when in the other Austrian provinces, the point estimate is larger and statistically significant (0.003 vs. 0.005).

Our results show that participation in stool test screening is increased to a much greater extent than participation in colonoscopy screening by the various CRC screening programs. However, since colonoscopies are only performed once every ten years, our program effect estimates based on a single year underestimate the program's overall impact. Our RD estimates with increasing window size indicate that most colonoscopy participants undergo screening within the first two years of availability (Tables S9-S11 in Supplementary file 4). These results suggest that the full VSP effect is likely to be less than 10 pp, even when accounting for insurees who undergo screening after the recommended age of 50.

A possible demand side reason for the overall much smaller impact on colonoscopy compared to stool tests could be a preference for less invasive screening methods. We only find few sex differences in the impact of the programs. However, the reasons for non-participation and the preference for a stool test over a colonoscopy may differ by sex. It has been shown that men tend to procrastinate more when deciding whether to be screened, while women are more likely to be concerned about receiving a diagnosis.[14,57]

From the supply side, our results call into question whether programs offering colonoscopies as the first screening tool can meet demand. One reason for this larger impact after two years is that many insurees who wanted to participate in CRC screening using a colonoscopy at age 50 when they were first eligible for the VSP or the GHSP had to wait until the following year for an appointment. Gaps in gastroenterology capacity in Austria exist, and rising future needs have been estimated.[43,58]

We find the high-organized program to increase participation in CRC screening the most. However, this program's two-step design requires a subsequent colonoscopy when the stool test is positive. Considering the evidence of the lower participation in follow-up testing in general as well as among those who receive a positive stool test result,[59-61] further research should focus on the impact of the different screening programs on cancer diagnostics.

The strengths of the study include the use of claims data from the largest health insurance provider for the entire Austrian population, which enables precise estimation of screening participation. Therefore, the estimates of the causal impacts of the screening programs on participation are representative of the Austrian population. To assess the generalizability of these estimates to other countries, we can use the population-based screening program with the highest degree of organization (BSP), which has been implemented in different European countries. Our participation estimates are similar to those found in other countries.[31,32]

However, the study is also limited by the use of claims data only. While the data provide precise information on screening participation, they do not include the screening results or other individual information such as the socioeconomic status. To the extent that socioeconomic status correlates with both province of residence and screening participation, our estimates may at least partly reflect compositional differences between provinces rather than pure program effects. That said, province fixed effects mitigate this concern by absorbing time-invariant regional differences in population composition within our DD estimates. Socioeconomic information would also be valuable for future work on potential differences in the causal effects of the three programs by socioeconomic status, and for understanding the effects of CRC screening programs on socioeconomic inequalities in screening participation and cancer-related outcomes.

Conclusions

We found that the organization of screening programs and the chosen testing strategy are important factors in increasing participation. The results of this paper are relevant both to researchers interested in the behavioral responses to screening programs that vary according to their degree of organization and to policy-makers when considering different screening tools, age eligibility ranges, screening frequency, and organizational structure for their CRC screening programs. For Austria, the paper provides a thorough evaluation of the existing CRC screening programs, informing policy-makers of their options and the potential uptake if they were to wish to establish a nationwide OSP.

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Disclosure of artificial intelligence (AI) use

During the revision of this work, the authors used Claude AI to check grammar, perform proofreading and shorten some parts of the text. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Ethical issues

This paper uses confidential and pseudonymized administrative data from the largest public health insurance provider in Austria. Data access was granted to us with a personal data transfer agreement. The pseudonymized dataset was kept and analyzed on a secure server, and its access restricted to the authors.

Conflicts of interest

Authors declare that they have no conflicts of interest.

Authors' contributions

Conceptualization: Andreas Fischeneder, Marcel Bilger, and Sophie Guthmuller.
Data curation: Andreas Fischeneder.
Formal analysis: Andreas Fischeneder.
Investigation: Andreas Fischeneder, Marcel Bilger, and Sophie Guthmuller.
Methodology: Andreas Fischeneder and Sophie Guthmuller.
Project administration: Marcel Bilger and Sophie Guthmuller.
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Supervision: Marcel Bilger and Sophie Guthmuller.
Validation: Andreas Fischeneder, Marcel Bilger, and Sophie Guthmuller.
Visualization: Andreas Fischeneder and Sophie Guthmuller.
Writing–original draft: Andreas Fischeneder and Sophie Guthmuller.
Writing–review & editing: Andreas Fischeneder, Marcel Bilger, and Sophie Guthmuller.

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Supplementary files

Supplementary file 1. Data.
Supplementary file 2. Empirical Strategy.
Supplementary file 3. DD Estimates.
Supplementary file 4. RD Estimates.

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