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RWI – Leibniz-Institut für Wirtschaftsforschung e.V.
Hohenzollernstraße 1–3 | 45128 Essen, Germany
Fon: +49 201 8149-0 | email: rwi@rwi-essen.de
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Hohenzollernstr. 1-3, 45128 Essen, Germany

Ruhr-Universität Bochum (RUB), Department of Economics
Universitätsstr. 150, 44801 Bochum, Germany

Technische Universität Dortmund, Department of Economic and Social Sciences
Vogelpothsweg 87, 44227 Dortmund, Germany

Universität Duisburg-Essen, Department of Economics
Universitätsstr. 12, 45117 Essen, Germany

Bergische Universität Wuppertal, Schumpeter School of Business and Economics
Gaußstraße 20, 42119 Wuppertal

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Direct and Indirect Effects of Cancer Screening Invitations on Participation in Europe: A Quasi-Experimental Analysis

Sophie Guthmuller* [1] [2], **Vincenzo Carrieri** [2] [3] [4], **Ansgar Wübker** [2] [5]

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Abstract:
Organized cancer screening programs (OSPs) in Europe for breast, cervical, and colorectal cancers aim to improve early detection and reduce mortality. This study measures the effects of OSPs on participation and examines cross-program spillovers, as women are often invited to multiple screenings. We construct a regional-level dataset on OSP availability, merged with individual-level data from the European Health Interview Survey (EHIS) covering 122,000 women in 27 countries. We exploit cross-region and age-based variations in eligibility and employ a quasi-experimental difference-in-differences model to measure the causal effect of OSPs. OSPs substantially increase screening participation: mammography rises by 33.20 percentage points (pp) (95% CI: 24.56–41.85), fecal occult blood test (FOBT) by 19.41 pp (95% CI: 13.95–24.88), and pap test by 9.33 pp (95% CI: 5.26–13.41). Positive spillover effects occur when women are invited to two screenings (10 pp (95% CI: 4.81–15.20) for mammography, 3.35 pp (95% CI: 0.56–6.15) for pap test, 7.44 pp (95% CI:2.34–12.55) for FOBT) but targeting three cancers does not yield additional statistically significant gains. These findings highlight the strong impact of OSPs on participation and the value of coordinated screening and communication strategies as Europe expands organized screening to new cancer sites.

Keywords: Organized Screening Programs, screening participation, cancer screening, cross-program spillovers; Europe

JEL codes: D90, H51, I12, I18, J18

[1] Health Economics and Policy group, Department of Socioeconomics, Vienna University of Economics and Business, Welthandelsplatz 1, Building D4, 1020 Vienna, Austria.
sophie.guthmuller@wu.ac.at ORCID: https://orcid.org/0000-0002-9115-304X
[2] RWI-Leibniz Institute for Economic Research, Hohenzollernstr. 1-3, 45128 Essen, Germany.
Ansgar.Wuebker@rwi-essen.de ORCID: https://orcid.org/0000-0002-7159-2846
[3] Department of Political and Social Sciences, University of Calabria, 87036 Rende (CS), Italy.
vincenzo.carrieri@unical.it ORCID: https://orcid.org/0000-0001-8742-3820

[4] Forschungsinstitut zur Zukunft der Arbeit (IZA), Schaumburg-Lippe-Straße 5–9, 53113 Bonn, Germany
[5] Hochschule Harz, Friedrichstraße 57-59, 38855 Wernigerode, Germany,
* Correspondence to: sophie.guthmuller@wu.ac.at

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Introduction

Cancer is the second leading cause of death worldwide, accounting for one in six deaths and a substantial share of disability-adjusted life years (DALYs) (Global Burden of Disease Cancer Collaboration 2022). Despite advances in therapy and precision medicine, late-stage diagnosis continues to limit survival gains. For example, while the five-year survival rate for localized breast cancer exceeds 90%, it falls to 30% for metastatic cancer (American Cancer Society 2024). Early detection through screening is therefore a cornerstone of cancer control.

Screening strategies differ across health systems. In the United States, screening is predominantly opportunistic and patient-initiated, whereas most European countries have adopted organized screening programs (OSPs). These OSPs systematically invite eligible individuals at regular intervals, free of charge, and provide balanced information on benefits and harms (Council of the EU 2003, 2022; IARC 2025; Zhang et al. 2022). Strong evidence indicates that OSPs improve early diagnosis and reduce cancer mortality. Biennial invitations to breast cancer screening have been linked to a 10% reduction in mortality among women in their mid-fifties (Van Ourti et al. 2020). Likewise, OSP implementation has been shown to increase mammography uptake by 25 percentage points and reduce mortality by 10% within a decade (Guthmuller, Carrieri, and Wübker 2023). Colorectal cancer screening programs demonstrate even larger effects, with mortality reductions of 30% (Mandel et al. 1999; Hewitson et al. 2008) and up to 41.8% with long-term implementation (Ding et al. 2024).

Nevertheless, participation remains below recommended levels, with marked variation across regions and socioeconomic groups (Gianino et al. 2018; Albers et al. 2023). A recent scoping review of the German OSP found participation rates falling short of EU targets and are strongly shaped by income, migration background, rural versus urban residency, and type of health insurance (Pedrós Barnils et al. 2024).

While most studies address barriers such as financial costs, information gaps, or individual risk perceptions, little attention has been given to interactions across programs. In practice, women are often invited to multiple screenings (e.g. breast, colorectal, cervical), raising the possibility of spillover effects across cancer screening programs. Multiple invitations may reinforce preventive behaviors, but they could also overwhelm individuals and reduce participation. Evidence from other domains suggests both mechanisms are plausible. For instance, (Carpenter and Lawler 2019) showed that mandatory Tdap vaccination in the United States increased uptake of other adolescent

vaccines through parental awareness and provider engagement. Similarly, workplace screening initiatives have documented peer spillovers in prevention uptake (Wolf et al. 2022).

To date, however, no empirical study has evaluated spillover effects across cancer screening programs. Understanding whether overlapping invitations enhance participation or create unintended overload is important for optimizing coordination and improving the efficiency of OSPs at both regional and European levels. This paper makes two contributions. First, it provides causal evidence on the effect of invitations to organized screening programs on the uptake of the three cancer screening programs in Europe. Second, it examines whether such invitations generate cross-program spillover effects—either reinforcing or crowding out participation in other screenings. By distinguishing between the direct and indirect (spillover) effects of invitations, the study sheds new light on the design of coordinated prevention policies.

To produce these findings, (i) we construct a regional dataset at the NUTS 2 level covering breast, colorectal, and cervical cancer screening programs and merge this dataset with individual-level records from the European Health Interview Survey (EHIS), which provide information on health status, healthcare use, and socioeconomic characteristics for over 122,000 women across 27 countries. (ii) We identify the causal direct and indirect effects of OSPs by using variation in regional availability of OSPs and variation in OSP target ages and follow a quasi-experimental Difference-in-Differences (DiD) approach. Quasi experimental designs, like DiD, yield credible evidence where there is lack of feasibility of randomized trials (Wing, Simon, and Bello-Gomez 2018).

Recent studies, including evaluations of breast and colorectal cancer OSPs in Europe, demonstrate the strength of these designs to produce robust population-level evidence.(Chauca Strand et al. 2024; Guthmuller, Carrieri, and Wübker 2023; Carrieri and Wuebker 2016).

Finally, we put our analysis in the context of the European Union Council Recommendations of 2003 (Council of the EU 2003), which fostered all Member States to implement OSPs for breast, cervical and breast cancer to reduce mortality by early detection. The European Cancer Screening Strategy (Council of the EU 2003, 2022) is described in detailed in the methods section.

Methods

European Cancer Screening Strategy

In 2003, the European Union recommended EU countries to introduce cancer screening programs for breast, cervical and colorectal cancer to increase early detection and reduce cancer prevalence and mortality (Council of the EU 2003).

Since this recommendation, implementation of screening programs has increased and most countries in Europe have introduced organized screening programs (OSPs) or population-based screening programs for at least one of these three cancer sites (Basu et al. 2018). An OSP defines the eligible population, the screening intervals, and the type of examinations. Within an OSP, the eligible population is identified and systematically invited to each round of screening with a personalized letter (IARC 2025). The EU recommends mammography screening for women aged 50 to 69 for breast cancer. For colorectal cancer, the recommended screening is a fecal occult blood test (FOBT) for men and women aged 50–74. At the EU level, screening for cervical cancer with a Pap test is recommended to start between the ages of 20 and 30 (Council of the EU 2003).

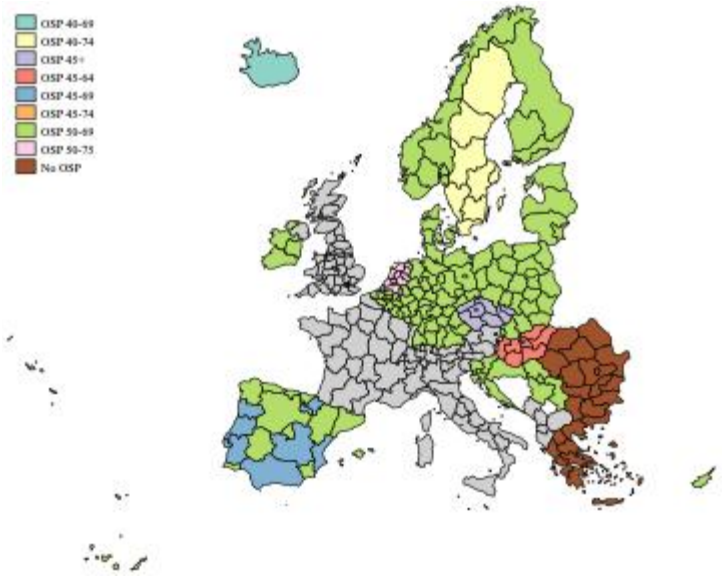
At national or regional level, variations exist in the way OSPs have been implemented. In 2019, the most frequent target population of OSPs for breast cancer is 50-69. However, several European regions have enlarged the target population to younger women starting at 40 years, and or to older women up to 75 years (see Figure 3 and Table S1). All OSPs for breast cancer invite eligible women for mammography every two years. For colorectal cancer, the EU's recommendation for cancer screening is usually to use a FOBT as the primary screening tool. The test kit is often sent to the patient's home. Invitations are sent every two years. Colonoscopy is most frequently used as second tier screening tool after an abnormal FOBT, but in some OSPs, colonoscopy is also offered as an alternative to FOBT. When this is the case, colonoscopy is offered every 10 years (Basu et al. 2018). In this paper, we focus on OSPs for colorectal cancer that offer a FOBT as screening examination to be able to study the existence of potential spillover effects of regular sending of invitations. Invitation for FOBT screening is sent every two years. As of 2019, the wider target age range for FOBT is 50-75. Some regions have chosen a smaller target population (see Figure 3 and Table S1).

In 2019, as for the other two OSPs, OSPs for cervical cancer implemented in EU regions have chosen different age targets: the earliest start age is 20 years old, the older end age is 70 years old (see Table S1 and Figure 3). Invitations are sent every three years for most of the OSPs. Some

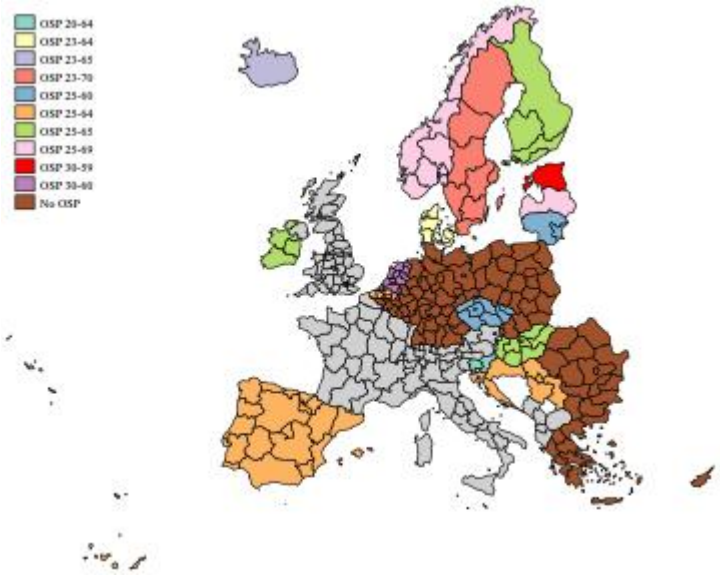
OSPs offer cervical cancer screening every five years, for example the 30-59/60 programs in the Netherlands and Estonia (Basu et al. 2018). In 2022, EU recommendations on screening have been updated and generally extend the age targets of the OSPs defined in 2003 (Council of the EU 2022).

Not all EU regions have implemented OSP for the three cancer sites. As of 2019, among the 195 EU regions included for analyses in this paper, few had not yet implemented any of three OSPs (EU regions of Romania, Greece, and Bulgaria), all other EU regions had at least an OSP for one of the three cancer sites in place (see Figure 3 and Table S1).

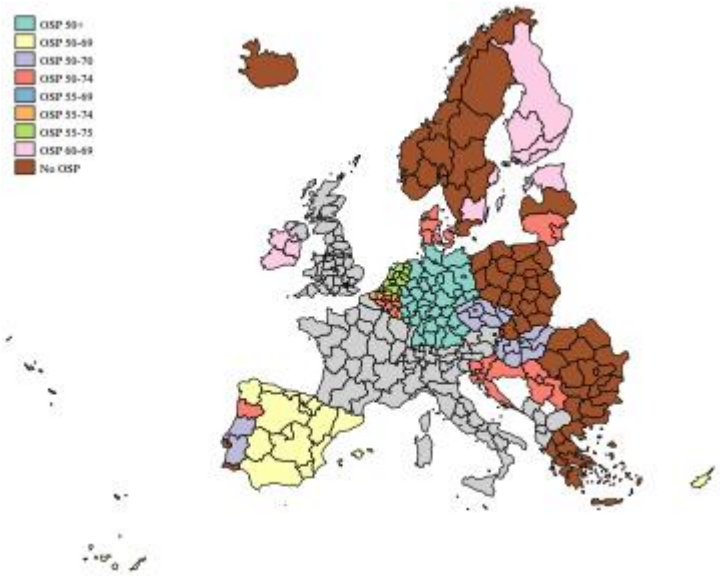
Figure 3 Organized cancer screening programs in Europe



(a) Organized screening programs for breast cancer



(b) Organized screening programs for cervical cancer



(c) Organized screening programs for colorectal cancer (FOBT)

Note: OSP = Organized Screening Program. No OSP = regions with no Organized Screening Program. Colored regions are those included in the analyses. *Source:* Authors‘ own database, 2019.

Data

We construct a regional dataset covering breast, colorectal, and cervical cancer screening programs, drawing on International Agency for Research on Cancer (IARC) factsheets (IARC 2020), reports (IARC 2016; European Commission 2017; Finnish Cancer Registry 2020), and

published studies (Basu et al. 2018; Vale et al. 2019; Bruni et al. 2022; Ola et al. 2024; Deguara, Calleja, and England 2020; Rigby et al. 2024; Cardoso et al. 2020; Cardoso, Hoffmeister, and Brenner 2023). Information on the three OSPs was collected at the NUTS 2 level: whether an OSP is in place, the year of introduction, the screening invitation intervals, the type of screening test and the target population. Figure 3 and Table S1 summarize the target populations of each OSP. For colorectal cancer, we consider only the programs that use an FOBT as screening tool. Programs with colonoscopy only and target age for colonoscopy are not listed.

These regional data on OSPs are merged with individual level data from the most recent European Health Interview Survey wave 3 (EHIS 3) that took place between 2018 and 2020 in 29 countries (Eurostat 2022). EHIS 3 was conducted in 2019 in all EU member states, Iceland, Norway, and Serbia. Except for Belgium where the interviews took place in 2018, and in 2020 in Germany and Malta. EHIS includes four modules on health status, health care use, health determinants and socio-economic background variables. EHIS is run every five years and targets the population aged at least 15 years and living in private households (Eurostat 2022). Our three outcomes of interest, measuring self-reported individual level cancer screening participation, are defined as follows: (1) whether a woman had a mammography screening in the last two years (2); whether a woman had a fecal occult blood test (FOBT) screening in the last two years; (3) whether a woman had a pap test in the last three years. Age in years and an indicator of the region of residence (at the NUTS 2 level) are used to identify whether a woman is in the target group of each of the three OSPs.

A set of control variables are also included. Educational attainment is measured by ISCED 2011, aggregated into three levels (low, medium, high). Income is measured with the net monthly equalized income of the household in quintiles. Labor status is defined as being employed, unemployed (including women fulfilling domestic tasks, students, pupils, in compulsory military or civilian service, women unable to work due to a longstanding illness) or retired. Type of household is a categorical variable differentiating between one person household, one parent with children, couple without children, couple with children under 25 years old, couple with children older than 25 years old, and other types of households. Degree of urbanization is defined as densely populated areas (cities), intermediate density areas (towns and suburbs), thinly populated areas (rural areas) (Eurostat 2025). The dataset also includes information on women's health status based on their general self-perceived health (in 4 categories: very good, good, fair, bad or very bad) and whether they report long-standing health problem(s).

Sample

The study sample includes data from women aged 17 to 90 years old from 27 countries. We excluded data from Italy because age was not available in years. Women aged 15–16 and women above 90 years were also excluded, as these age groups were not consistently covered across countries. We kept all women with information on mammography, FOBT, and pap test. (We deleted proxy interviews.) Some of the confounding factors had missing values. We accounted for those by adding a category for missing values in the analyses, to keep all women with self-reported screening participation in the sample. The study sample includes 122,952 observations. Table S2 presents the steps of the sample construction.

Estimation strategy

As descriptive analysis, we first plot respectively, the proportion of women who had a mammography in the last two years, who had a pap test in the last three years, and who had an FOBT in the last two years at NUTS 2 level. We then plot screening participation for each of the three cancers by age, for each OSP defined by their target age. Based on these plots, we visually investigate whether screening participation increases when age is within each OSP target age. If this is the case, this would give use descriptive evidence that OSPs have a positive effect on screening participation.

Next in multivariate quasi-experimental analysis (Guthmuller, Carrieri, and Wübker 2023), we estimate the average program effect of OSPs on participation. To estimate the causal effect of the OSP, we rely on a Difference-in-Differences type strategy. This approach compares changes in screening participation between women who are eligible for the program and those who are not, across regions with and without OSPs. In this way, the estimated effect can be attributed to the program itself, rather than to pre-existing differences between regions or age groups that may influence also the screening participation. Formally, the model is specified as follows:

$$S_{ir} = \beta_0 + \beta_1 Region_r + \beta_2 Age_i + \beta_3 Treatment_{ir} + \beta_4 Controls_{ir} + e_{ir} \qquad \text{eq. 1}$$

where S_{ir} indicates whether woman *i* living in region *r* screened, within the last 2 years for breast cancer and colorectal cancer, and within the last 3 years for cervical cancer. $Treatment_{ir}$ is our variable of interest and is equal to one if woman *i* is eligible to the OSP i.e. has an age within the

age range targetted by the screening programme and lives in a region r where the OSP is in place. $Region_r$ and Age_i are respectively region fixed effects and age (in years) fixed effects. These fixed effects are key to the Differences-in-Differences estimation strategy. They allow us to isolate the OSP effect from confounders varying at regional level (i.e., general attitude towards prevention, average education and income) and confounders at age level (i.e. variation in the individual risk of being diagnosed with a cancer which varies across ages) that may influence screening decision irrespective of an OSP invitation. $Controls_{ir}$ denotes the set of demographic, socioeconomic and health variables that are added to test the sensitivity of our estimates. e_{ir} is the error term. Identification of the program effect relies on regional variation in the availability of OSPs and variation in age targets. These variations are essentially related to the high degree of autonomy of regional health authorities in Europe for what concerns the definition of the target population. As regional heterogeneity largely depends on region-specific orientations toward the target population and not on other factors potentially related to screening participation and OSP implementation (i.e., evidence on region-specific age-cancer risks profiles) it allows us to treat it as good as random in our setting. The direct causal effect is estimated for breast, colorectal, and cervical cancers separately. We use robust standard errors clustered at NUTS-2 level.

To distinguish the direct from potential spillovers effects of being eligible to more than one OSP, we re-estimate equation 1 where $Treatment_{ir}$ is replaced by a categorical variables taking the following values: *None* when woman *i* living in region *r* is eligible to none of the three OSPs (either because she resides in a region with no OSP in place or because she is not in the target age of any of the three programs); one *OSP* when woman *i* is eligible to one OSP (either because she lives in a region where only one of three OSPs is introduced or because she is in a the target age of only one program), namely the one corresponding to the outcome of interest; *OSP+*, in addition to the OSP targeted by the outcome of interest, woman *i* is eligible to a second OSP because she lives in a region where at least two OSPs are implemented and she is in the target age of two programs; or *OSP++,* woman *i* is eligible to the breast, cervical and colorectal cancer screening programs because she lives in a region where the three OSPs are implemented and because she is in the target age of the three programs.

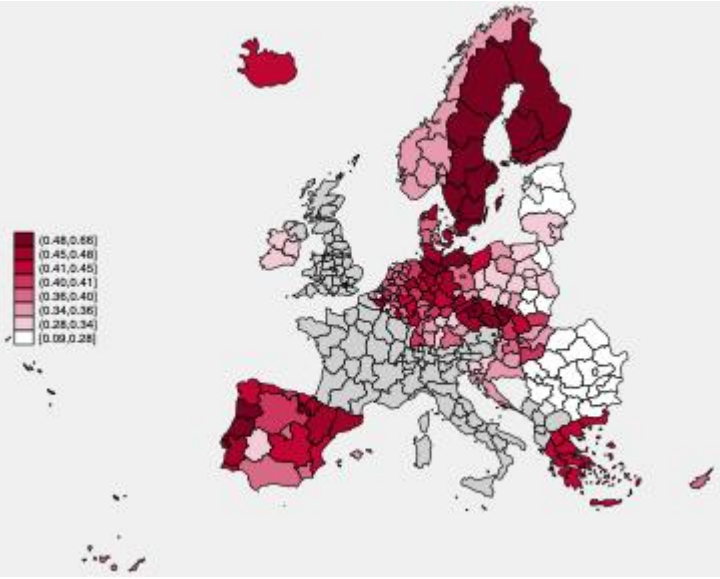
Results

Descriptive statistics

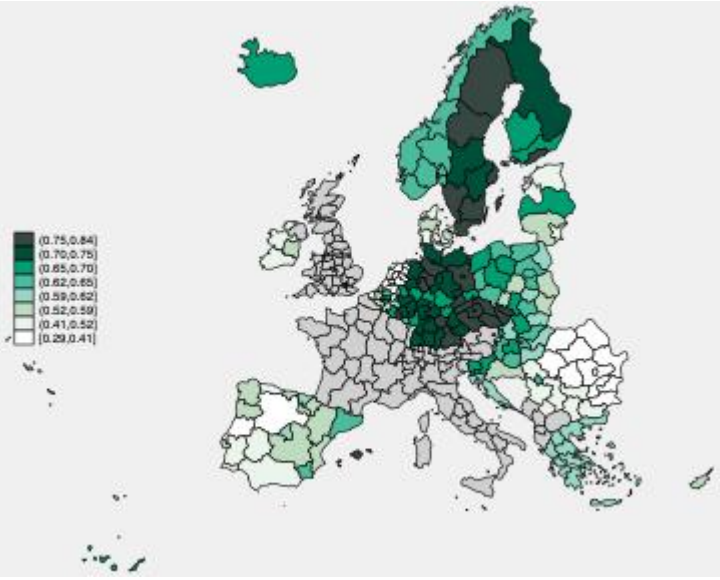
Screening uptake varies substantially between European regions and cancer sites. For mammography, uptake ranges from 8.6% to 65.6% (median 40%). For FOBT, lower uptakes are observed with a median of 19.9 % (range 0.1–50%), while for cervical cancer screening, there are higher uptakes (median 61.7 %, range 28.9–84.1%).

These regional differences are illustrated in Figure 1. Panel a shows mammography use, panel b Pap test use, and panel c FOBT use.

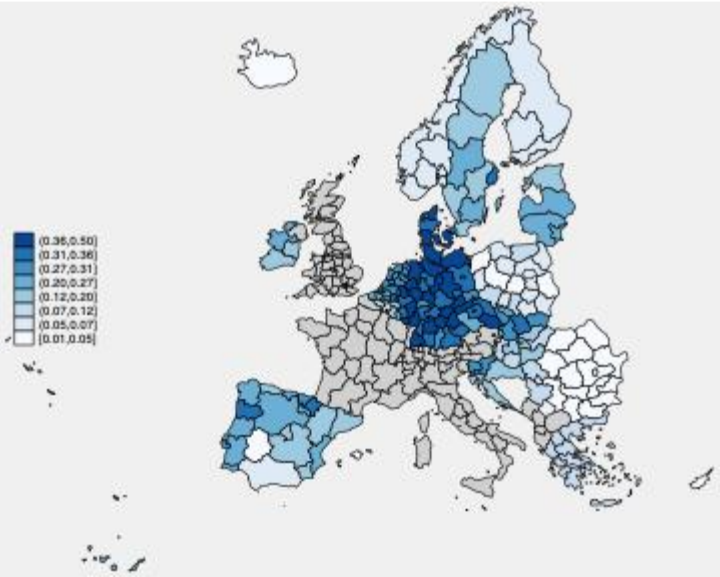
Figure 1: Screening participation in European regions



(a) Mammography uptake in the last two years



(b) Pap test uptake in the last three years



(c) FOBT uptake in the last two years

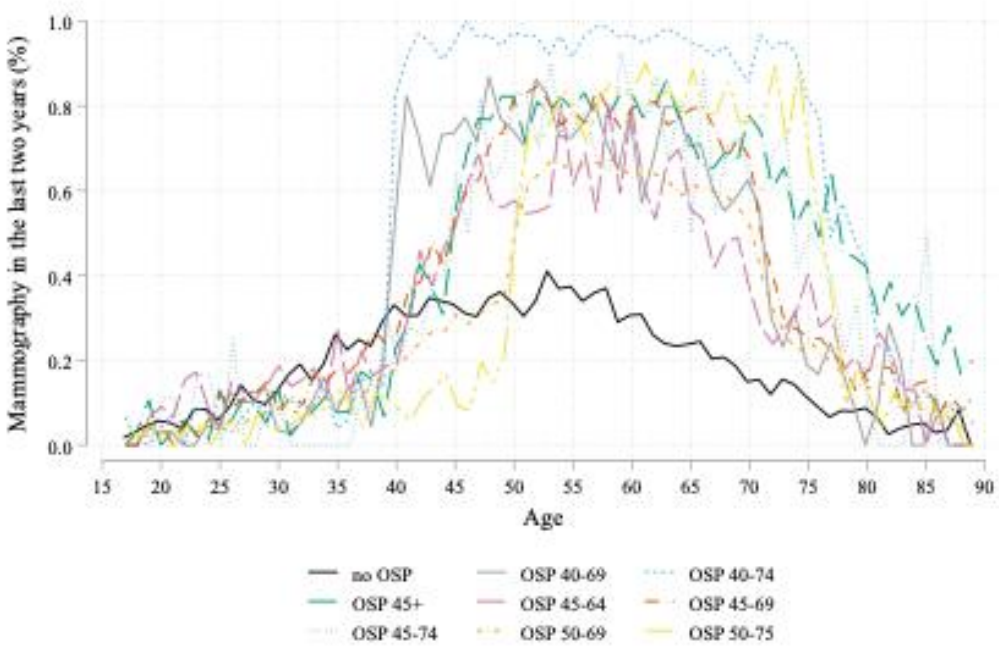
Note: The screening rate is defined as having had a (a) mammography in the last two years; (b) a Pap test in the last three years; (c) an FOBT in the last two years; among women aged between 17 and 90 years in each region divided by the respective population of women aged 17-90 years in each region. Authors‘own calculations on EHIS – Eurostat data, 2019

Figure 2 displays screening participation by age for each OSP defined by their target age. Panel a reports screening participation for breast cancer, panel b for cervical cancer, and panel c for colorectal cancer. Screening uptake sharply increases at the starting age of each OSP and sharply

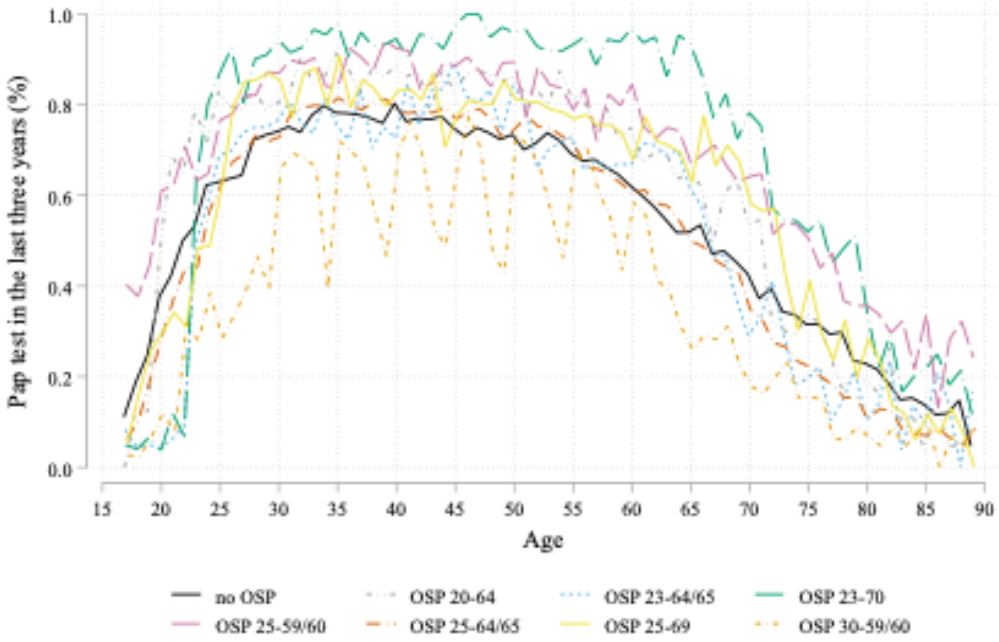
declines at the end of the target age range. For instance, participation in mammography screening among women living in a region with an OSP 50-69 years, is 33.7% (with 95% confidence interval: 28.8%–38.6%) at 49, 64.1% (60.2%–68.1%) at age 52, 55.7% (50.2%–51.2%) at 69 years old and 30.7% (27.5%–34.0%) at 72. At the same ages, in regions without OSPs, participation is 36.1% (31.4%–40.8%) at 49, 33.9% (29.3%–38.5%) at age 52, 18.7% (14.6%–22.8%) at 69, and 11.9% (7.3%–16.6%) at age 72 (Figure 2, panel a).

We observe a similar pattern for colorectal cancer screening. In regions with organized screening programs (covering ages 50–74), FOBT uptake is 9.3% (95% Confidence Interval - CI: 6.7%–11.8%) at age 49, 39.0% (27.0%–50.0%) at age 52, 30.0% (19.3%–40.6%) at age 74, and 21.2% (15.6%–26.8%) at age 77. In regions without OSPs, uptake at the same ages is lower: 7.5% (4.1%–10.8%) at 49, 13.6% (7.0%–20.2%) at 52, 15.7% (9.9%–21.5%) at 74, and 12.6% (6.3%–18.9%) at 77 (Figure 2, panel c). Screening uptake for cervical cancer rises sharply between 20 and 30 years old, both in OSP and non-OSP regions. The sharp increase of the non-OSP-regions is explained by the number of EU regions that have screening programs for cervical cancer screening without an invitation system (Zhang et al. 2022; Vale et al. 2019). Women who go to the GP or to the gynecologist in a certain age range are offered a free Pap test every three or five years (Vale et al. 2019). However, the visual inspection of Figure 2, panel b shows that the increase is generally higher for OSP–regions compared to non-OSP regions, and screening participation declines at the upper age limit of each OSP. The higher levels in OSP regions plausibly mirror systematic invitation and recall procedures.

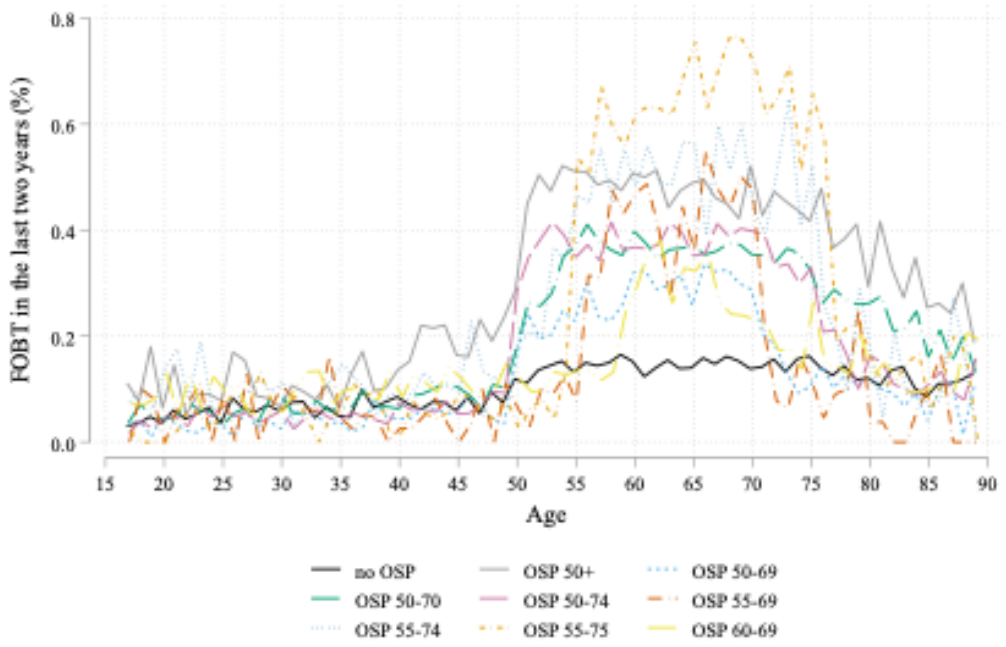
Figure 2: Screening participation by age, and OSPs and non-organized screening programs.



(a) Breast cancer



(b) Cervical cancer



(c) Colorectal cancer

Note: (a) Rate of mammography uptake in the last two years; (b) rate of Pap test uptake in the last three years; (c) Rate of FOBT uptake in the last two years, by OSP target ages and regions with non-organized screening, raw data. Authors‘ own calculation based on EHIS data, 2019.

Average causal effects

Table 1 presents the causal estimates of the effect of OSP on screening participation based on equation 1. OSP for breast cancer increases mammography participation by 33.21 percentage points (pp) (95% Confidence Interval:24.56-41.85) on average. The impact of OSP on colorectal cancer screening participation is 19.41 pp (95% CI:13.95-24.88), and the effect of OSP on cervical cancer screening participation is 9.33 pp (95% CI:5.26-13.41) on average (Table 1, col 1, 3, and 5). The findings remain robust after adding control variables e.g. for age, education, marital status, employment, urbanicity, and self-reported health (Table 1, col 2, 4, and 6). Table S4 reports the full estimation outputs including the coefficients for the control variables. The causal effect of OSP for cervical cancer is substantially smaller in size compared to the effects of OSP for breast and colorectal cancer. This is explained by a large participation rate of 47.44% of women had a pap test in the last three years in the control group, which includes programs without an invitation

system (Zhang et al. 2022; Vale et al. 2019). For breast and colorectal cancers, screening participation in the control group is lower and corresponds mainly to opportunistic screening (18.6% for breast cancer and 10.7% for colorectal cancer, Table 1).

Table 1: Direct effects

	(1) mammo	(2) mammo	(3) pap	(4) pap	(5) fobt	(6) fobt
Treatment	0.332***	0.333***	0.0933***	0.0903***	0.194***	0.197***
	(0.0438)	(0.0432)	(0.0206)	(0.0202)	(0.0277)	(0.0274)
N	122,952	122,952	122,952	122,952	122,952	122,952
Mean control group (%)	18.60	18.60	47.44	47.44	10.67	10.67
St. dev. control group (%)	38.91	38.91	49.93	49.93	30.87	30.87
Age fixed effects	X	X	X	X	X	X
Region fixed effects	X	X	X	X	X	X
Confounding factors		X		X		X

Note: Region level clustered standard errors are in parentheses. The control group includes women who are not eligible for OSP because they live in a non-OSP region or because they are outside of the target age of the region specific OSP. Statistical significance: *** p<0.01, ** p<0.05, * p<0.1

Direct and indirect causal effects

Table 2 reports the estimated effects of OSP, distinguishing between: OSP (direct effect only), OSP+ (direct effect plus eligibility for one additional screening), and OSP++ (direct effect plus eligibility for two additional screenings). These estimates include the set of control variables (see Table S6 for the detailed output including the coefficients of each control variable). The direct effect of OSP is 25.70 pp (95% CI:18.06-33.30) for breast cancer, 8.18 pp (95% CI:4.17-12.19) for cervical cancer, and 13.72 pp (95% CI:9.37-18.07) for colorectal cancer.

The impact of OSP+ that is the direct effect of OSP for breast cancer and the indirect effect of another OSP on the probability of mammography uptake is 35.68 pp (95% CI:26.99-44.38). Thus, the cross-program spillover effect of receiving an invitation to screen for another cancer on mammography uptake is 10.00 pp (95% CI: 4.81-15.20): OSP+ is 10 pp larger than OSP only

(0.357- 0.257). Table 2 column 1; the test of coefficient equality is rejected with a p-value of 0.000 (t-value:3.80). Positive spillover effects are also found for cervical and colorectal cancer screening; the cross-program spillover effect of receiving a screening invitation for another cancer is 3.35 pp 95% CI: 0.56-6.15 (11.5-8.18, t-value:2.37,p-value: 0.019) on pap test uptake, and 7.44 pp 95% CI:2.34-12.55 (21.2-13.7, t-value:2.88, p-value: 0.005) on FOBT uptake. However, receiving a third invitation to screen for another cancer (i.e. being eligible for the three OSPs) does not significantly change participation compared to being eligible for two OSPs. Table S5 reports causal estimates of the direct and indirect effects excluding the set of control variables.

Table 2: Cross program spillover effects

	mammo	t-test p-value	pap	t-test p-value	fobt	t-test p-value
OSP	0.257***	OSP – OSP++:	0.0818***	OSP – OSP++:	0.137***	OSP – OSP++
	(0.0386)	0.0006	(0.0203)	0.7355	(0.0220)	0.0004
OSP +	0.357***	OSP – OSP+	0.115***	OSP – OSP+	0.212***	OSP – OSP+
	(0.0440)	0.0002	(0.0252)	0.0190	(0.0351)	0.0045
OSP ++	0.369***	OSP+ OSP++	0.0866***	OSP+ OSP++	0.220***	OSP+ OSP++
	(0.0509)	0.5651	(0.0215)	0.0768	(0.0314)	0.7925
N	122,952		122,952		122,952	
Mean control group (%)		18.60		47.44		10.67
St. dev. control group (%)		38.91		49.93		30.87

Note: Region level clustered standard errors are in parentheses. Each column is a different regression. All regressions include age and region fixed effects, and the set of control variables. The control group includes women who are not eligible for OSP because they live in a non-OSP region or because they are outside of the target age of the region specific OSP. *** p<0.01, ** p<0.05, * p<0.1

Discussion

We studied the causal effect of OSPs for breast, cervical, and colorectal cancer on screening participation in Europe using regional data on OSPs characteristics and individual level data on screening participation and information on socioeconomic, demographic, health and health care use from the European Health Interview Survey (EHIS). To identify the causal effects, we followed a Differences-in-Differences approach using variation in the availability of OSP across European regions and variation in the target age of the OSPs. This strategy allows us to separate the effect of the program from regional and age-related factors that could otherwise confound the results. We measured the average causal effect of OSP for each cancer site. We distinguished between the direct effect of OSP on screening participation from potential cross-program spillover effects of being eligible for more than one OSP.

Our findings show that OSP significantly increases screening participation: the average causal effect of OSP for breast cancer is 33 pp in a sample of 27 EU countries in 2019, which is larger in size than previous studies in Europe found (Guthmuller, Carrieri, and Wübker 2023; Carrieri and Wuebker 2016); (Carrieri and Wuebker 2016) estimated an effect of 17 pp on a subset of 13 EU countries in 2006; (Guthmuller, Carrieri, and Wübker 2023) estimated an effect of 25 pp on a subset of 21 EU countries in 2014. There are several factors that may contribute to this trend. These include the increasing average invitation rate over time (Giordano et al. 2012), a higher intensity of invitations for programs that have been running longer, and advancements in screening techniques and breast cancer treatments that enhance the benefits of screening (Hong and Xu 2022).

We found an average OSP effect for colorectal cancer with FOBT of around 20 pp. Although direct comparisons with the sparse previous evidence are limited, this EU-wide causal estimate is lower than those of other country-specific studies in Europe (Francetic, Meacock, and Sutton 2022), but higher than the estimates found in the United States, where screening is only covered by health insurance for certain target ages and no equivalent OSP is in place (Bitler, Carpenter, and Horn 2021), and is in line with the current trends estimated in CRC screening utilization in studies using the EHIS survey (Ola et al. 2025). The impact of OSP for colorectal cancer is also lower than for breast cancer. Different reasons could explain this, among those, specific impeding factors related to the screening procedure or a perceived lower risk for colorectal cancer (Bocci et al. 2015) among the target population. The more recent implementation of OSPs for colorectal cancer, where

invitation rates have not yet reached the rates of OSPs for breast cancer is another reason (Basu et al. 2018; Ponti et al. 2017; Vale et al. 2019).

For cervical cancer, the average causal effect (9 pp) is smaller than the other two cancer sites, as for cervical cancer, many European regions have cervical cancer screening programs with a lower level of organization in place that do not include an invitation system of the target population (Vale et al. 2019) among the criteria defining a screening program (Zhang et al. 2022). Participation in pap test is therefore much higher in non-OSP-regions (50%), as women have access to pap test screening within their regular reproductive health checkup at the GP or gynecologist. This is not the case in non-OSP-regions for breast and colorectal cancers, where screening outside of the OSP is merely opportunistic or symptomatic screening (Basu et al. 2018).

In addition to a positive direct effect of each of the three OSPs on screening participation, we found significant positive cross-program spillover effects when women are in the target population of two OSPs i.e. are receiving two invitations to screen for two different cancer sites. However, being in the target population of the three OSPs compared to two does not further increase participation nor decreases it. These findings are particularly relevant to help design coordinated cancer screening policies and communication strategies, and this even more in light of the implementation of OSP for other cancer sites, such as lung cancer (Wait et al. 2022; European Observatory on Health Systems and Policies 2025) in the near future.

A major strength of this study is the use of a large, representative dataset covering more than 122,000 women across 27 European countries, which provides strong external validity and allows for meaningful cross-country comparisons. The application of a Difference-in-Differences approach with regional and age fixed effects strengthens the causal interpretation of the results. Another important contribution is the novel examination of cross-program spillovers, which had not been systematically studied before.

Nonetheless, some limitations should be acknowledged. First, despite the rich dataset, the analysis relies on self-reported screening outcomes from the EHIS, which may be subject to recall bias or misreporting. Second, although regional variation in OSP implementation provides a strong identification strategy, unobserved or time-varying contextual differences across regions—though uncommon—may still confound the results. Third, the study focuses only on FOBT-based colorectal screening programs, which may limit generalizability to regions where colonoscopy is

the primary test. Finally, the cross-sectional nature of the EHIS data restricts the ability to assess longer-term behavioral dynamics or repeated participation across screening rounds.

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Appendix

Table S1 Target population of the organized screening programs (OSPs)

Country	Breast cancer	Cervical cancer	Colorectal cancer
Belgium	50-69	25-64	50-74
Bulgaria	none	none	none
Cyprus	50-69	none	50-69
Czech Republic	45+	25-60	50-70
Germany	50-69	20-65	50+
Denmark	50-69	23-64	50-74
Estonia	50-69	30-59	60-69
Greece	none	none	none
Spain	45-69 50-69	25-64	50-69
Finland	50-69	25-65	60-69
Croatia	50-69	25-64	50-74
Hungary	45-64	25-65	50-70
Ireland	50-69	25-65	60-69
Iceland	50-69	23-65	none
Lithuania	50-69	25-60	50-74
Luxemburg	50-69	none	55-74
Latvia	50-69	25-69	none
Malta	50-69	25-64	55-69
Netherlands	50-75	30-60	55-75
Norway	50-69	none	none
Poland	50-69	25-59	none
Portugal	45-74 50-69	25-60 25-64	50-70 50-74 none
Romania	none	none	none
Serbia	50-69	25-64	50-74
Slovenia	50-69	20-64	50-74
Slovakia	50-69	23-64	none
Sweden	40-74	23-70	60-69 none

Note: Target population of Organized screening programs (OSPs) receiving regular invitation to screen as 2019. Countries with more than one target population are those where the target age range differs by region. For colorectal cancer, the target population considered is the one for FOBT.

Table S2: Sample construction

Sample of women (EHIS 3 version downloaded in May 2025)	N=167,112
Exclusion of Italy and Austria	N= 134,723
Exclusion of 15, 16 and over 90 years old	N= 131,234
Exclusion of missing or proxy replies for pap, mammography, and fobt	N=122,952

Table S3 Descriptive statistics

	Means	**Std. dev.**
OUTCOMES		
Mammography in the last 2 years	.3580666	.4794338
Pap test in the last 3 years	.5792179	.4936866
FOBT in the last 2 years	.1790943	.3834328
DIRECT EFFECT: treatment		
Breast cancer	.3580096	.4794169
Cervical cancer	.377383	.4847339
Colorectal cancer	.2614598	.4394316
SPILLOVER EFFECT:		
Breast cancer		
None	.6419904	.4794169
OSP	.0609099	.239166
OSP+	.1918879	.393787
OSP++	.1052118	.3068274
Cervical cancer		
None	.622617	.4847339
OSP	.1943767	.3957217
OSP+	.0777946	.2678492
OSP++	.1052118	.3068274
Colorectal cancer		
None	.7385402	.4394316
OSP	.0412763	.1989293
OSP+	.1149717	.3189891
OSP++	.1052118	.3068274
CONFOUNDING FACTORS:		
Age (min:17, max:90)	53.30134	18.17531
Educational attainment		
Low	.2797921	.4488988
Medium	.4012704	.4901575
High	.3136915	.4639945

Missing	.0052459	.072239
Net monthly equalized income		
< 1st quintile	.1830796	.3867333
1st quintile - 2nd quintile	.198549	.3989093
2nd quintile - 3rd quintile	.1870811	.3899782
3rd quintile - 4th quintile	.1864223	.3894487
4th quintile - 5th quintile	.1770854	.3817425
Missing	.0677825	.2513734
Labor status		
Employed	.4507694	.4975725
Unemployed	.2331886	.422863
Retired	.3110075	.4629078
Missing	.0050345	.0707756
Type of household		
One-person household	.2330991	.4228065
Lone parent with children	.0524432	.22292
Couple without children	.2626065	.4400522
Couple with children <25	.2361409	.4247115
Couple with children >25	.0509223	.21984
Other type of household	.1558657	.3627295
Missing	.0089222	.0940354
Degree of urbanization		
Densely-populated	.3630604	.480884
Intermediate-populated area	.2945052	.4558219
Thinly-populated area	.2905443	.4540154
Missing	.0518902	.2218062
Self-perceived health		
Very good	.2154093	.4111076
Good	.4120795	.4922113
Fair	.2709757	.4444654
Bad or very bad	.0970704	.2960548
Missing	.0044652	.0666728
Long-standing health problem		
Yes	.4554623	.4980145
No	.5383158	.4985318
Missing	.0062219	.0786338
N	**122,952**	

Table S4 Treatment effect of OSP on participation

VARIABLES	(1) **Mammography**	(2) **Pap test**	(3) **FOBT**
Treatment	0.333***	0.0903***	0.197***
	(0.0432)	(0.0202)	(0.0274)
Educational attainment *(ref: Low)*			
Medium	0.0435***	0.0710***	0.00852
	(0.00735)	(0.00655)	(0.00536)
High	0.0551***	0.109***	0.0155**
	(0.00992)	(0.00809)	(0.00639)
Missing	0.0120	0.00588	0.0306
	(0.0175)	(0.0235)	(0.0218)
Net monthly equalized income *(ref:< 1st quintile)*			
1st quintile - 2nd quintile	0.0118**	0.0222***	0.00684*
	(0.00469)	(0.00576)	(0.00396)
2nd quintile - 3rd quintile	0.0250***	0.0384***	0.00668
	(0.00516)	(0.00683)	(0.00467)
3rd quintile - 4th quintile	0.0419***	0.0595***	0.00305
	(0.00500)	(0.00572)	(0.00606)
4th quintile - 5th quintile	0.0681***	0.0804***	0.0140*
	(0.00704)	(0.00682)	(0.00756)
Missing	0.0371***	0.0569***	0.00801
	(0.00680)	(0.00958)	(0.00668)
Labor status (*ref: Employed*)			
Unemployed	-0.0202***	-0.0435***	-0.000749
	(0.00395)	(0.00599)	(0.00356)
Retired	-0.0163	-0.0291**	-0.0179**
	(0.0110)	(0.0116)	(0.00873)
Missing	-0.00296	-0.0391*	-0.00543
	(0.0173)	(0.0207)	(0.0177)
Type of household *(ref: One-person household)*			
Lone parent with children	0.0163**	0.0549***	-0.0110*
	(0.00740)	(0.00800)	(0.00573)
Couple without children	0.0343***	0.0425***	0.0180***
	(0.00531)	(0.00500)	(0.00551)
Couple with children <25	0.0189***	0.0567***	-0.0135***
	(0.00584)	(0.00546)	(0.00502)
Couple with children >25	0.0124	0.00804	0.00375
	(0.00793)	(0.00870)	(0.00816)
Other type of household	0.00412	-0.00394	-0.00598
	(0.00540)	(0.00638)	(0.00374)
Missing	0.0215**	0.0110	-0.00174
	(0.00990)	(0.0118)	(0.0142)

Degree of urbanization *(ref: Densely-populated)*			
Intermediate-populated area	-0.00720	-0.0179***	0.00310
	(0.00449)	(0.00608)	(0.00535)
Thinly-populated area	-0.0208***	-0.0290***	-0.00144
	(0.00614)	(0.00695)	(0.00480)
Missing	-0.0306***	-0.0308***	0.0259***
	(0.00583)	(0.00711)	(0.00506)
Self-perceived health *(ref: Very good)*			
Good	-0.00482	-0.00259	-0.00220
	(0.00540)	(0.00525)	(0.00432)
Fair	-0.0102	-0.0191***	0.0197***
	(0.00803)	(0.00724)	(0.00593)
Bad or very bad	-0.0177**	-0.0363***	0.0420***
	(0.00797)	(0.00988)	(0.00671)
Missing	-0.000993	-0.0892***	0.0128
	(0.0266)	(0.0283)	(0.0217)
Long-standing health problem			
Yes	0.0171***	0.0235***	0.0211***
	(0.00388)	(0.00395)	(0.00379)
Missing	-0.0109	0.00124	-0.00230
	(0.0189)	(0.0193)	(0.0183)
N	122,952	122,952	122,952
Mean control group	18.60	47.44	10.67
Std. dev. control group	38.91	49.93	30.87

Note: Estimations include region and age fixed effects. Region level clustered standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table S5 Cross program spillover effects

	mammo	t-test p-value	pap	t-test p-value	fobt	t-test p-value
OSP	0.255***	OSP – OSP++:	0.0856***	OSP – OSP++:	0.133***	OSP – OSP++
	(0.0382)	0.0007	(0.0208)	0.9731	(0.0220)	0.0002
OSP +	0.357***	OSP – OSP+	0.122***	OSP – OSP+	0.210***	OSP – OSP+
	(0.0447)	0.0002	(0.0270)	0.0322	(0.0355)	0.0040
OSP ++	0.367***	OSP+ OSP++	0.0861***	OSP+ OSP++	0.218***	OSP+ OSP++
	(0.0511)	0.6634	(0.0215)	0.0538	(0.0315)	0.8040
N	122,952		122,952		122,952	
Mean control group (%)	18.60		47.44		10.67	
St. dev. control group (%)	38.91		49.93		30.87	

Note: Region level clustered standard errors are in parentheses. Each column is a different regression. All regressions include age and region fixed effects. *** p<0.01, ** p<0.05, * p<0.1

Table S6 Cross program spillover effects: including confounding factors

VARIABLES	(1) **Mammography**	(2) **Pap test**	(3) **FOBT**
Treatment *(ref: none)*			
OSP	0.257***	0.0818***	0.137***
	(0.0386)	(0.0203)	(0.0220)
OSP +	0.357***	0.115***	0.212***
	(0.0440)	(0.0252)	(0.0351)
OSP++	0.369***	0.0866***	0.220***
	(0.0509)	(0.0215)	(0.0314)
Educational attainment *(ref: Low)*			
Medium	0.0455***	0.0709***	0.0106**
	(0.00728)	(0.00653)	(0.00520)
High	0.0562***	0.109***	0.0173***
	(0.00991)	(0.00812)	(0.00624)
Missing	0.0146	0.00840	0.0322
	(0.0174)	(0.0230)	(0.0218)
Net monthly equalized income *(ref:< 1st quintile)*			
1st quintile - 2nd quintile	0.0112**	0.0222***	0.00676*
	(0.00471)	(0.00573)	(0.00393)
2nd quintile - 3rd quintile	0.0242***	0.0383***	0.00711
	(0.00519)	(0.00684)	(0.00471)
3rd quintile - 4th quintile	0.0406***	0.0593***	0.00349
	(0.00494)	(0.00572)	(0.00599)
4th quintile - 5th quintile	0.0662***	0.0799***	0.0140*
	(0.00697)	(0.00689)	(0.00738)
Missing	0.0361***	0.0567***	0.00817
	(0.00672)	(0.00955)	(0.00666)
Labour status (*ref: Employed*)			
Unemployed	-0.0205***	-0.0434***	-0.000263
	(0.00399)	(0.00600)	(0.00351)
Retired	-0.0122	-0.0283**	-0.0145*
	(0.0105)	(0.0114)	(0.00798)
Missing	-0.00317	-0.0405**	-0.00479
	(0.0172)	(0.0205)	(0.0178)
Type of household *(ref: One-person household)*			
Lone parent with children	0.0151**	0.0548***	-0.0108*
	(0.00759)	(0.00800)	(0.00579)
Couple without children	0.0347***	0.0426***	0.0179***
	(0.00532)	(0.00496)	(0.00551)
Couple with children <25	0.0180***	0.0566***	-0.0134***
	(0.00597)	(0.00548)	(0.00502)
Couple with children >25	0.0115	0.00846	0.00378

	(0.00793)	(0.00868)	(0.00813)
Other type of household	0.00418	-0.00397	-0.00621
	(0.00541)	(0.00636)	(0.00377)
Missing	0.0217**	0.0104	-0.00229
	(0.0100)	(0.0118)	(0.0141)
Degree of urbanization *(ref: Densely-populated)*			
Intermediate-populated area	-0.00732	-0.0181***	0.00315
	(0.00447)	(0.00605)	(0.00535)
Thinly-populated area	-0.0209***	-0.0293***	-0.00167
	(0.00611)	(0.00692)	(0.00478)
Missing	-0.0307***	-0.0309***	0.0254***
	(0.00587)	(0.00711)	(0.00513)
Self-perceived health *(ref: Very good)*			
Good	-0.00482	-0.00193	-0.00217
	(0.00542)	(0.00513)	(0.00438)
Fair	-0.00876	-0.0185**	0.0197***
	(0.00817)	(0.00721)	(0.00600)
Bad or very bad	-0.0176**	-0.0361***	0.0413***
	(0.00805)	(0.00995)	(0.00675)
Missing	0.000800	-0.0886***	0.0133
	(0.0266)	(0.0284)	(0.0220)
Long-standing health problem			
Yes	0.0174***	0.0236***	0.0206***
	(0.00388)	(0.00395)	(0.00379)
Missing	-0.0116	0.000850	-0.00240
	(0.0189)	(0.0192)	(0.0185)
N	122,952	122,952	122,952
mean control group	18.60	47.44	10.67
Std dev. control group	38.91	49.93	30.87

Note: Estimations include region and age fixed effects. Region level clustered standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1