How Effective is National Breast Cancer Screening? Evidence from a Regression Discontinuity on French Data

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Abstract

This paper evaluates the effectiveness of France's national breast cancer screening, introduced in 2004 for women aged 50-74, in reducing breast cancer mortality amid suboptimal participation. Using mortality data from CépiDc (2005-2021) across 13 regions and regional screening participation rates, I document significant disparities in both mortality and program uptake. To estimate the program's causal impact, I implement a parametric Fuzzy Regression Discontinuity Design, using age-based eligibility as an instrument for actual participation, to address *imperfect compliance*. The results show that while programme eligibility significantly reduces mortality, low participation rates attenuate its effect, limiting the impact to roughly half of the estimated intent-to-treat effect. Non-parametric robustness checks support these findings. Quantification indicates that the programme has saved hundreds of lives annually across regions. These results demonstrate that population-based screening can provide substantial public health benefits, but achieving its full potential depends critically on effective engagement.

Keywords: Health Policy, Breast Cancer, France, Causal Inference, Mortality
JEL Classification: C14, C26, I12, I14, I18

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1 Introduction

Breast cancer is the most commonly diagnosed and deadliest cancer among women worldwide, with significant variations in incidence and mortality across countries (Bray et al., 2018; Motoi and Niţă, 2021). Global incidence increased by 0.5% to 1.5% annually from 1975 to 2000 before stabilising from 2005 to 2012, yet it remains a major public health challenge, with late-stage diagnosis and inadequate clinical follow-up contributing to 23% related deaths (Akram et al., 2017; Lei et al., 2021; Arnold et al., 2022). Projections suggest a 40% rise in new cases by 2040, driven by population growth and ageing demographics. Reproductive, hormonal, and behavioural risk factors, along with disparities in screening and socioeconomic status, further affect breast cancer incidence and mortality (Aljohar, Kilani et al., 2018; Xia et al., 2016; Bellanger et al., 2018; Lei et al., 2021).

In France, breast cancer incidence is approximately 45% higher than the European average, although mortality rates remain comparable (Jéhannin-Ligier et al., 2017; Dyba et al., 2021). Since the late 1970s, incidence has risen sharply, while mortality has gradually declined since 1995, reflecting improvements in early diagnosis and treatment (Binder-Foucard et al., 2014; Sancho-Garnier and Colonna, 2019). To further reduce breast cancer mortality and address health inequalities, the French government launched the National Breast Cancer Screening Program (NBCSP) in 2004, offering free biannual mammography at accredited radiological centres to women aged 50-74 without significant risk factors. The program combines clinical breast examination, mammography, and double reading of normal mammograms to improve diagnostic accuracy and minimise false positives (Ouédraogo et al., 2015). The effectiveness of such population-based programs relies on high screening uptake, timely follow-up, and efficient healthcare organisation (Arveux et al., 2003; Schopper and Wolf, 2009). Although the NBCSP became the largest screening initiative in the European Union by 2009, it has struggled to meet the European target of 70% participation, which is considered necessary to significantly reduce mortality (Perry et al., 2008). Participation peaked at 52.3% in 2011-2012 and fell to 47.7% in 2021-2022, partly due to the COVID-19 pandemic. Moreover, uptake varies widely

across regions - from over 60% in some areas to below 30% in others - reflecting disparities in income, education, healthcare access, minority status, and proximity to screening facilities (Pornet et al., 2010; Ouédraogo et al., 2014; Deborde et al., 2018).

A particular concern is the rising incidence of breast cancer among women under 50, who now account for 15% of new cases and often experience more aggressive disease and lower survival rates (Anders et al., 2008; Colonna et al., 2008; Fleurier et al., 2018; Hassaine et al., 2022). For women aged 40–50, incidence increased by 32% between 1990 and 2023 (Institut National du Cancer, 2023; Lapôtre-Ledoux et al., 2023). Because the NBCSP excludes women below 50, many undergo opportunistic screening, sparking debates on whether the program should extend eligibility to those aged 40–49 (Pivot et al., 2011; Ouédraogo et al., 2015; Le Parisien, 2023). International guidelines differ: the European Commission and Council recommend starting at 45, whereas the American Cancer Society advises beginning at 40 (Duffy et al., 2020).

Given the rising incidence among women and sub-optimal participation in the NBCSP, evaluating the program's effectiveness on breast cancer mortality is critical. While prior studies have shown that the NBCSP increases mammography uptake and reduces inequalities - Buchmueller and Goldzahl (2018) reported improved participation among women aged 50–74 in France, and Carrieri and Wuebker (2016) observed a 24% increase in uptake in 13 European countries using home invitations - evidence on its direct impact on breast cancer mortality in France remains limited. Evidence from the USA illustrates the potential of population-based screening: Kadiyala and Strumpf (2016) estimated a 109% increase in breast cancer detection rates at the recommended age by using a regression discontinutiy design. This paper contributes to the literature by assessing the impact of population-based breast cancer screening on mortality using a comprehensive dataset from 13 regions from 2005 to 2021. The contributions of this paper are threefold. First, it uses a rich dataset that matches mortality data from CéPiDc for women aged 25-74, screening participation rates from Santé Publique, socioeconomic variables from Insee, and regional healthcare data from the Institut National du Cancer, including hospitals

offering cancer treatment and Regional Cancer Screening Coordination Centres (CRCDCs). This integration enables robust analysis of screening participation and its heterogeneous effects, highlighting disparities in mortality and uptake across regions.

Second, the study employs a parametric Fuzzy Regression Discontinuity Design (RDD) to estimate the marginal impact of the NBCSP on mortality at the guideline-recommended age threshold of 50. Because participation is voluntary and influenced by personal preferences, age-based eligibility does not perfectly determine treatment, leading to *imperfect compliance*. The Fuzzy RDD addresses this by using the exogenous assignment to the treatment, *eligibility*, as an instrumental variable for *effective participation*, allowing for a more accurate estimation of the NBCSP's impact on mortality. By comparing women just above and below the age threshold, any observed jump in mortality rates near the cut-off can be interpreted as evidence of a treatment effect.

Third, findings show that assignment to the treatment around the threshold increases the probability of participation by approximately 3.90 percentage points and significantly reduces mortality. Two-stage least squares (2SLS) estimates indicate that sub-optimal participation limits the program's effect on mortality to roughly half of the intent-to-treat effect. Additional factors, such as the number of hospitals offering breast cancer treatment and the presence of CRCDCs, also contribute to mortality reduction. Robustness checks using non-parametric methods with varying bandwidths and kernel functions, as well as standard RDD validity tests (Imbens and Lemieux, 2008; Lee and Lemieux, 2010), confirm these findings.

This study provides new evidence on the benefits of screening at the recommended age and identifies factors influencing the effectiveness of the NBCSP in France. These findings could guide French policymakers in developing strategies to improve the program's impact and increase participation rates.

The rest of the paper is structured as follows. Section 2 provides an overview of the relevant literature. Section 3 describes the dataset. Section 4 outlines the methodology. Section 5 presents the empirical findings. Section 7 reports robustness checks. Section 8 concludes the paper and discusses policy implications.

2 Related literature

2.1 Breast cancer screening in France

The French national breast cancer screening programme (NBCSP) targets women aged 50 to 74, without apparent symptoms or specific risk factors of developing breast cancer other than their age (Assurance Maladie, 2024). The programme was initially implemented locally in the 1980s and subsequently expanded from 10 to 32 departments by 2000. It became national in 2004 as part of a cancer plan strategy aimed at reducing cancer incidence and mortality across France (Appendix A).

The programme is overseen by the Minister of Health and coordinated by multiple stakeholders, including the General Director of Health (DGS), the Director of Social Security and health insurance organisations (e.g., CNAMTS, MSA, RSI). The French National Institute for Cancer (INCa) provides expert reports, manages communications, and designs documents for the screening programme, while *Santé Publique France* is responsible for its epidemiological evaluation. Regional Cancer Screening Coordination Centres (CRCDCs) oversee regional implementation, supporting regional health agencies, managing screening, training healthcare professionals, ensuring follow-up and system quality, and collecting data.

Every two years, eligible women receive an invitation letter from the CPAM explaining the benefits of mammography and organised screening, including double reading. The invitation also includes a care voucher and a list of participating radiologists, selected by the National Cancer Institute and Assurance Maladie. Screening is fully covered by the national health system and provided free of charge. It includes two mammographic images per breast, a clinical breast examination, and an ultrasound scan if any abnormalities are detected. Suspicious results lead to an immediate diagnostic follow-up, while normal results undergo a second reading to minimise false positives and improve breast cancer detection (Thurfjell et al., 1994). The double reading is perceived by women participating in the programme as an indicator of quality (Kalecinski et al., 2015). [1] Participation in the programme remains

[1] *First reader radiologists* must undergo specific training, perform a minimum of 500 mammograms per year, and have their equipment inspected by a national agency. *Second reader radiologists* must

voluntary (INCA, 2024).

The programme aims to implement a quality assurance system aligned with European screening recommendations, although it continues to fall short of participation targets. Organised programmes typically increase screening rates through educational outreach, by providing information on screening benefits and service accessibility, by ensuring full financial coverage that removes cost barriers, and by offering a perceived higher level of quality compared with opportunistic screening. Evidence shows that organised screening increases the likelihood of regular screening and encourages participation (Goldzahl and Jusot, 2016; Buchmueller and Goldzahl, 2018).[2] Despite these advantages, women may still choose opportunistic screening by obtaining a prescription from a physician and paying out-of-pocket. However, this option does not include a second radiologist's review, a combined clinical breast examination, performance monitoring, and standardised quality measures. Moreover, unlike the NBCSP, it does not follow a two-year invitation cycle that ensures systematic follow-up. Access to such services is further shaped by socioeconomic status, the extent of health insurance coverage, rural residence, and the socioeconomic characteristics of one's residential area (Ouédraogo et al., 2015; Deborde et al., 2018; Quintin et al., 2022).

2.2 Inequalities in breast cancer screening participation

France ranks fourth among 19 OECD countries in income-related inequalities in mammography usage, reflecting significant disparities in screening participation, prevention, treatment, and survival, despite efforts to improve breast cancer detection through population-based screening programs. Socioeconomic and cultural factors, as well as broader social injustices, continue to influence these disparities (Freeman and Chu, 2005; Palència et al., 2010; Devaux, 2015; Mootz et al., 2020).

Socioeconomic status (SES) is a critical determinant of screening uptake: women with

read at least 1500 mammograms annually to ensure consistent quality. These requirements are designed to maintain a national quality standard.

[2]If a mammogram is not completed within six months of receiving the invitation, a reminder is sent, followed by a second reminder six months later. Women in the target age range also receive a new invitation 20–22 months after their last mammogram or after their last invitation if they have never participated.

lower income, education, or employment stability, and those facing limited healthcare accessibility or insurance coverage, are less likely to participate in screening (Duport et al., 2008; Pornet et al., 2010; Jusot et al., 2012; Carrieri and Wübker, 2013; Menvielle et al., 2014; Menvielle et al., 2018). Ecological studies using material deprivation indices further show that socioeconomic environments strongly influence participation, with particularly low uptake in rural, peri-urban, and economically disadvantaged areas (Townsend, 1987; Ouédraogo et al., 2014; Ouédraogo et al., 2015; Guillaume et al., 2017; Deborde et al., 2018). Despite higher breast cancer incidence among women with higher SES, driven partly by reproductive histories, lifestyle behaviours, and more frequent screening, mortality rates remain lower in this group due to better access to timely and effective treatment (Lundqvist et al., 2016).

Infrastructural challenges, including transportation and healthcare accessibility, substantially affect screening participation and cancer registration, particularly in resource-constrained settings, and contribute to delayed breast cancer diagnoses and suboptimal treatment (Coughlin and Ekwueme, 2009). Bailly et al. (2023) introduced a *human development index* specific to Nice, identifying public transport access, family context, and professional status as key determinants in screening uptake. Consistent with Smith et al. (2019), the study reported lower screening rates in areas characterised by higher socioeconomic deprivation. Moreover, financial barriers often outweigh logistical constraints, as the absence of private complementary health insurance reduces the likelihood of undergoing a mammogram (Sicsic and Franc, 2014).

Organised screening programmes help reduce socioeconomic disparities by removing financial barriers and increasing awareness. Between 2000 and 2010, these programmes contributed to a 14% increase in mammography rates among women in the target age range in France, with particular strong benefits among women with lower SES and a measurable reduction in education- and income-related disparities (Buchmueller and Goldzahl, 2018). However, while organised screening reduces disparities within the middle class, it appears less effective for socio-economic extremes (Duport et al., 2008). Similarly, disparities in mortality rates persist, driven by

differences in hospital distribution, access to advanced treatment, and geographic accessibility.

Accessibility to screening facilities is a key determinant of participation. Proximity to healthcare resources or accredited radiology centres significantly increases screening uptake, while women living in rural areas or farther from screening sites are less likely to participate due to reduced access to medical services (Pornet et al., 2010; Ouédraogo et al., 2014). Similar patterns are observed in Sweden (Zidar et al., 2015) and the United States (Linsell et al., 2010), where strategically located units with good public transport connections and adequate parking facilities support higher participation rates. Studies have demonstrated the effectiveness of mobile mammography units (MMUs) in reaching women, reducing geographical and social inequalities in remote areas, and increasing participation in screening (Guillaume et al., 2017; De Mil et al., 2019). Furthermore, contact with general practitioners (GPs) and primary care physicians positively influences participation in organised screening (Pornet et al., 2010; Duport, 2012; Menvielle et al., 2018).

Persistent social and territorial disparities also characterise the use of opportunistic versus population-based screening. Rollet et al. (2021) show that departments with high rates of opportunistic screening tend to have lower participation in the national programme. High-income patients exhibit higher breast cancer incidence, partly due to more intensive follow-up, which further exacerbate screening disparities. Conversely, Quintin et al. (2022) report improved mammography access through organised screening between 2016 and 2017, although overall NBCSP coverage remains around 50%. More than one-third of women continue to rely on opportunistic screening - both within and outside the age range - particularly in departments with low organised screening participation rates.

2.3 Breast cancer detection in young women

Breast cancer is increasingly diagnosed among women aged 40–49, who now account for roughly 13% of new cases and for whom the disease remains the leading cause of mortality (Anastasiadi et al., 2017; Lanta et al., 2019). Since the 1990s, incidence among younger women has risen markedly in Europe, representing about 5% of cases

in France and 7% globallyy (Leclère et al., 2013). Evidence from Isère, France, from 1990 to 2018, shows a significant increase in diagnoses among younger women, attributed to earlier detection and advances in treatment (Hassaine et al., 2022). Younger patients are also more likely to present with aggressive tumour subtypes, leading to poorer prognoses and lower survival rates (Anders et al., 2008; Grimm et al., 2022).

The optimal age at which to initiate mammography remains debated, balancing benefits in cancer detection against potential drawbacks such as false positives, over-diagnosis, and radiation-related risks(Hendrick, 2010; Kowalski, 2021). Despite divergent recommendations across health authorities, there is consensus that more intensive screening reduces mortality (Grimm et al., 2022). International expert bodies, such as the WHO's International Agency for Research on Cancer, recommend biennial screening starting at age 50, a strategy associated with a roughly 20% reduction in mortality through earlier tumour detection (Perry et al., 2008; Duffy and Paci, 2012). By contrast, the U.S. Preventive Services Task Force advocates initiating screening at age 40.

In France, the effective threshold for mammography is closer to 45 years (Pivot et al., 2011), with significant demand for opportunistic screening among women aged 40-49 (Quintin et al., 2022). Evidence on mortality effects for this age group is mixed but generally supportive of earlier screening. Elmore et al. (2005) report a 20%-35% reduction in mortality for women aged 50-69 and a 14% reduction for those aged 40-49. Moss et al. (2015) similarly find significant reductions with annual screening beginning at 40. In Sweden, Hellquist et al. (2015) document a 29% decline in overall mortality for women invited to screening and a 18% reduction among women aged 40-44 age.

Earlier screening also reduces disease severity at diagnosis and the need for invasive and aggressive treatments. Women aged 40-49 who undergo screening are significantly less likely to undergo mastectomy, auxiliary node dissection, or chemotherapy compared to unscreened women (Ahn et al., 2018). Other studies confirm substantial benefits in terms of reduced morbidity, lower mortality, improved survival, and fewer years of life lost (Duffy et al., 2020; Zielonke et al., 2021). On the contrary,

Colonna et al. (2008) argue against systematic screening for women under 40, given the rarity of disease and diagnostic limitations, and emphasise prevention strategies targeting modifiable lifestyle choices and familial risk factors.

3 Data

This section describes the data used in the analysis before outlining the econometric methodology. The study relies on a strongly balanced panel covering the years 2005 to 2021 for 13 regions in Metropolitan France. Overseas regions, including La Réunion, Guadeloupe, Guyane, Martinique, and La Mayotte are excluded due to data inconsistencies, missing observations, and socioeconomic conditions that differ substantially from those of Metropolitan France. [3]

The final dataset comprises 2431 region–age–year observations and focuses on women aged 25 to 74. The population is divided into ten five-year age groups (25–29, 30–34, 35–39, etc.), each assigned a unique identifier. Detailed data sources are described in the following subsection, and summary statistics are reported in Appendix B (Table 9).

3.1 *Breast cancer mortality rate*

Data on age-specific female breast cancer mortality rates (per 100,000 inhabitants) by region and year from 2005 to 2021 were obtained from CépiDc, an INSERM laboratory and WHO collaborating centre. CépiDc has systematically recorded medical causes of death from death certificates since 1968 for metropolitan France and since 2000 for overseas regions. In collaboration with Insee, it produces annual national statistics on causes of death, covering roughly 570,000 deaths per year.

The database contains nearly 25 million records and provides three types of information: (1) the number of deaths and crude and standardised mortality rates by department, region, and major city (available directly on the CépiDc website); (2) detailed data on disease groupings, geographical areas, and place of death (available

[3] Some overseas regions have missing values in the existing database. For example, in the CépiDc database, data for Guyane and Mayotte are only available from 2001 and 2014 respectively, while in Santé Publique, the screening participation rate for La Mayotte is absent.

upon request and subject to CNIL authorisation); and (3) data required for cohort surveillance (also accessible upon request and CNIL authorisation).

Data are sourced from death certificates, which include both nominative and anonymous sections to ensure compliance with the 2004 Public Health Law on confidentiality. These certificates record the initial cause as well as contributing causes (immediate, intermediate, associated), along with demographic information such as sex, age, place of death, and place of residence. Causes of death are recorded according to the International Classification of Diseases (ICD-10) and the ICD-O sub-classification for oncology, following Eurostat's 86 categories since 2012.

To preserve age-specific information, the analysis relies on the *crude mortality rate* per 100000 inhabitants, originally classified into ten-year age groups, except for the youngest categories (<1 and 1-24). The *crude mortality rate* measures the number of deaths relative to the resident population and allows analysis for the spatio-temporal death distribution.[4]

To improve granularity, the original ten-year age groups were reclassified into five-year intervals. This reclassification was made to align with screening participation data and better fit the empirical strategy, consistent with standard demographic assumptions. Mortality patterns generally follow a J-shaped curve: low in early childhood (0-10 years), rising sharply during adolescence, and increasing exponentially by 8-10% annually, roughly doubling every 8-9 years, beyond age 35. On a logarithmic scale, this exponential increase is represented as a straight line. Estimation accuracy declines after age 95 due to reporting errors and small population sizes (Preston et al., 2001; Ined, 2018).

The reclassified age groups, presented in Table 1, allows for a more detailed analysis of mortality trends. The 1-24 age group was excluded from this study due to its minimal mortality rate.

[4]CépiDc also provides: (1) the *effective numbers of deaths*, quantifying the absolute volume of deaths and (2) the *standardised mortality rate*, adjusted to a standard age distribution.

Table 1: Age classification

Original Classification	New Classification	Age Identifier
1-24	1-24	1
25-34	25-29	2
	30-34	3
35-44	35-39	4
	40-44	5
45-54	45-49	6
	50-54	7
55-64	55-59	8
	60-64	9
65-74	65-69	10
	70-74	11

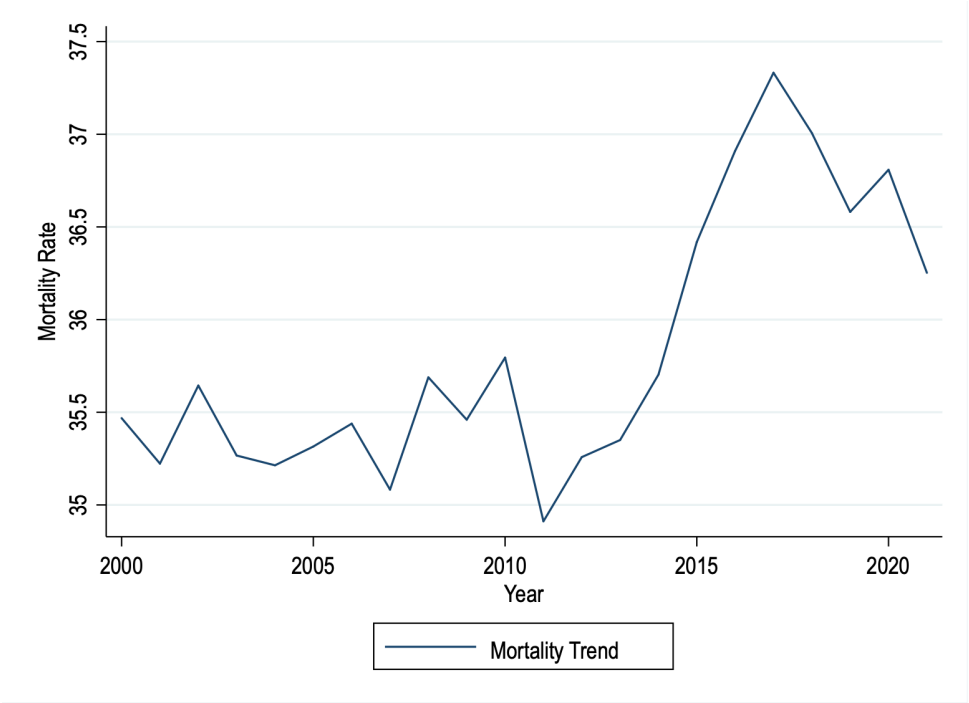
Notes: The original age classification was subdivided into five-year age groups to align with the study's objectives and improve data granularity. Each group has been attributed an age identifier (ID).

Figure 1 presents the national crude breast mortality rates per 100000 inhabitants over the period 2000-2021. Figure 1a illustrates a stable trend in mortality rates from 2000 until approximately 2010, followed by a steady and significant increase from 2010 to 2017. After peaking in 2017, the mortality rates began to decline slightly but remained high compared to the pre-2010 levels. Figure 1b shows age-specific mortality trends at the national level, indicating a decreasing trend for women aged 55-64 and 65-74 while remaining constant for younger women.

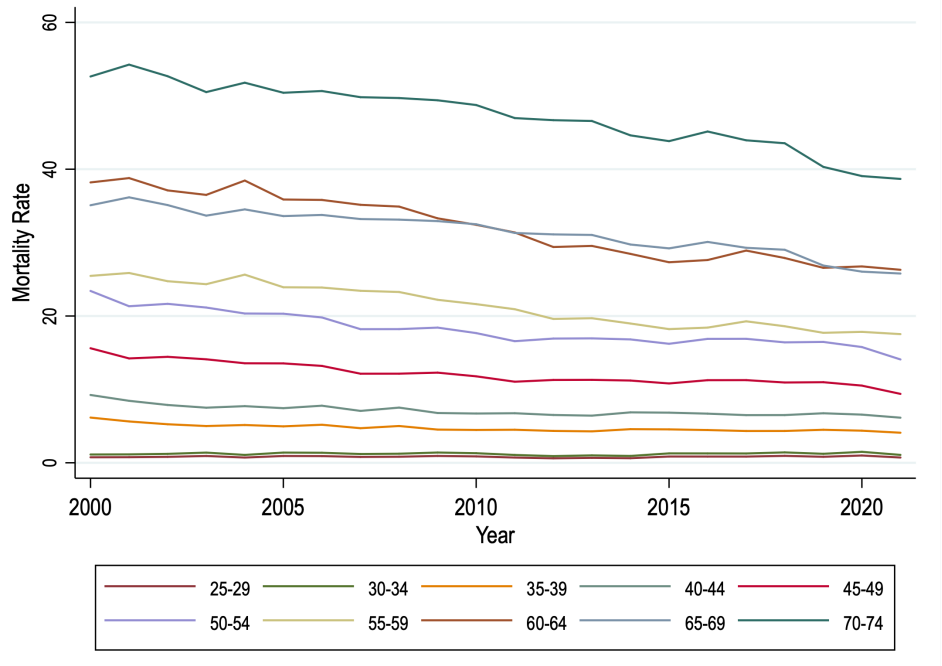
Supplementary figures in Appendix C (Figure 8) illustrate mortality trends over five-year intervals for Metropolitan France. These maps reveal significant regional disparities in mortality rates. The highest mortality rates are observed in Normandie and Centre-Val de la Loire, while the lowest in Île-de-France. This region's lower impact compared to others emphasises the variability in health outcomes across France and the need for targeted public health interventions to address the regional disparities in mortality rates across Metropolitan France.

Figure 1: Crude breast mortality rate (2005-2021) - Metropolitan France

(a) Aggregated



(b) Decomposed by age



Notes: Figure 1 shows the breast cancer mortality trends per 100000 inhabitants in Metropolitan France. Figure 1a shows the national aggregated trend, while Figure 1b presents the trend decomposed by age group.

3.2 *Screening participation rate*

Data on the percentage of women participating in the national breast cancer screening program (NBCSP) were provided by *Santé Publique France* upon request. These data include national and regional participation rates, categorised by five-year age groups (50-54, 55-59, 60-64, 65-69, 70-74), from 2005 to 2021. Participants' ages are determined as of December 31^{st} of the year before the screening.

Cancer epidemiological data in France come from regional cancer registries. CRCDCs are responsible for invitations, data collection of women participating in the screening programme, screening results, and follow-up. Data undergo validation and consistency checks at *Santé Publique France* before being processed and integrated into the NBCSP evaluation database, which includes data from nearly 2.5 million women annually. This database, though lacking socioeconomic information on individuals, is considered comprehensive and of high quality, serving as the basis for producing NBCSP performance indicators at both national and departmental levels (Quintin et al., 2022).

The evolution of national participation in organised breast cancer screening for five-year age groups in France from 2005 to 2020 is shown in Figure 2. Participation rates vary by age group, being highest for women aged 60-64 and lowest for those aged 70-74. Not all eligible women aged 50-74 who receive an invitation appear to participate in the national programme. Participation rates rose steadily until 2011-2012, reaching a peak of 52.3%, but then declined significantly, reaching their lowest point in 2020 due to the COVID-19 pandemic and the cessation of invitations by CRCDCs. In 2021, participation rates recovered in all age groups and regions, probably due to increased activity by CRCDCs and radiology practices to compensate for the decline in 2020.

Additional figures in Appendix D (Figure 9) illustrate regional participation trends over five years. The data show regional disparities, with low participation rates in Île-de-France and South-East France, and relatively high participation rates in Brittany, Centre Val de la Loire and Pays de la Loire over the years. Regional participation rates by age group are presented in Appendix E (Figure 10), revealing

heterogeneous trends across age and age groups.

Figure 2: Trends in national breast cancer screening program participation by age group (2005-2021)



Notes: (a) Author's realisation based on data provided by Santé Publique France. (b) The graph shows the breast cancer screening participation rate as a percentage of attending women, at the national level from 2005 to 2021. (c) Participation rates are reported per age group and aggregated by eligibility.

3.3 *Socioeconomic and health variables*

3.3.1 Socio-economic characteristics

The dataset includes regional socio-economic data from the French National Institute of Statistics and Economic Studies (INSEE). It contains *Regional Real GDP* and *GDP per capita* (expressed in millions of euros) to account for socio-economic disparities across regions, and *female population* classified by five-year age group.

Studies have shown that cancer incidence and mortality patterns vary with different GDP per capita levels (Yang et al., 2017). Regions with higher GDP and GDP per capita generally have better healthcare infrastructure and higher-quality medical services. These regions also tend to have higher levels of education and health literacy, which can lead to increased awareness of breast cancer and higher screening

participation rates. Additionally, controlling for population growth ensures that observed changes in mortality rates reflect the effectiveness of screening programs rather than demographic changes in population size.

3.3.2 Hospital distribution and accessibility

The dataset includes several healthcare variables, notably the number of hospitals per region offering cancer care treatments from 2005 to 2021. This data, sourced from the *Institut National du Cancer* and updated by the *Agence régionale de santé* (ARS), provides insights into hospital distribution, healthcare accessibility, and therapeutic innovation by region.

The French cancer care network includes 865 health establishments and authorised cancer treatment centres overseen by the ARS. These institutions are categorised by type, region, and department on an interactive map, which also includes contact details and treatment options. Authorisations for cancer treatment ensure uniform levels of safety, quality, and accessibility nationwide, developed in collaboration with the Ministry of Health, the National Cancer Institute, hospital federations, health professionals, and the League against Cancer, under a legal framework established in 2007.

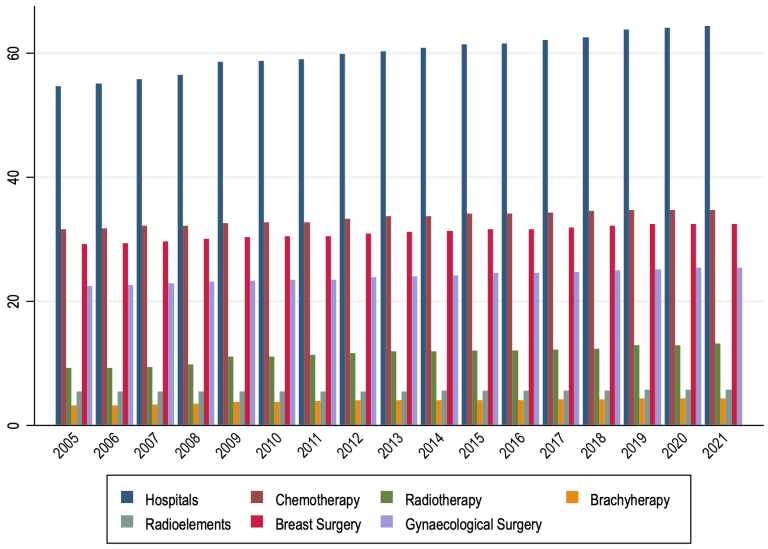
This study includes 841 hospitals categorised into Hospital Centres (public), University Hospital Centres (public), Cancer Centres (private non-profit health structures), Army Training Hospitals (HIA), Private for-profit hospitals, and Non-profit hospitals. These hospitals offer various treatments, including chemotherapy, radiotherapy, brachytherapy, radio-elements, breast surgery, and gynaecological surgery. The French cancer care network has been matched with the *Fichier National des Établissements Sanitaires et Sociaux* (FINESS) to track the opening year and observe annual changes in hospital distribution.

The distribution of these hospitals is shown in Figure 3. The proportion of hospitals offering cancer care treatments is less than the total number of hospitals, both over time (Figure 3a) and overall (Figure 3b). Chemotherapy and breast surgery are the most commonly provided treatments. Regional disparities are evident in the distribution of hospitals. For instance, in 2021, Île-de-France had the highest

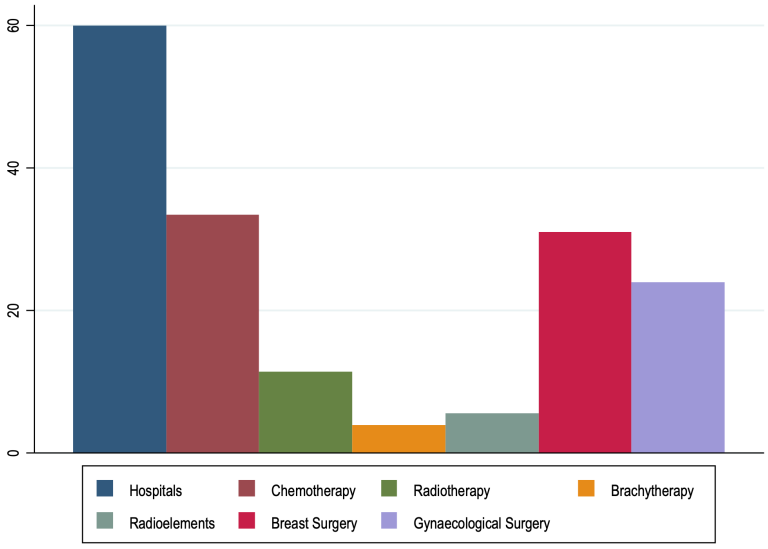
concentration of hospitals (142), with 85 offering chemotherapy and 68 providing breast surgery. Conversely, Corsica had the lowest concentration (7 hospitals), with only 3 offering chemotherapy and 2 providing breast surgery.

Figure 3: Hospital Distribution

(a) Over time (2005-2021)



(b) Cumulative distribution



3.3.3 Regional cancer screening coordination centres (CRCDCs)

The dataset includes the number of Regional Cancer Screening Coordination Centres (CRCDCs) per region and department, obtained from the French National Cancer Institute. Under the 2014-2019 Cancer Plan, the departmental structures have been centralised and merged into Regional Cancer Screening Coordination Centres (CRCDCs) to optimise resources and standardise cancer screening practices across regions. Each CRCDC manages territorial sites, typically one per department, and operates under the authority of the French Ministry of Health. Their role is to improve the efficiency of cancer screening programmes at the regional level by increasing participation rates, reducing disparities, and improving organisation, information dissemination, and programme evaluation.

4 Empirical strategy

4.1 Fuzzy regression discontinuity design

The Regression Discontinuity Design (RDD), introduced by Thistlethwaite and Campbell (1960), is a robust quasi-experimental comparison-group strategy where *treatment status* is determined by an assignment rule crossing a known cut-off point or threshold. By comparing units just above or below the cut-off point and assuming that the variation in the treatment around the cut-off is approximately random, RDD helps to isolate causal effect from confounding factors that might affect the outcome (Lee and Lemieux, 2010).

To isolate the causal impact of the National Breast Cancer Screening Program (NBCSP) on women's mortality, a *Fuzzy Regression Discontinuity Design* is used, exploiting the fact that assignment to the treatment is defined as a discontinuous function of age. In a *fuzzy* RDD, treatment assignment is probabilistic: the probability of receiving treatment changes discontinuously at the cutoff but not perfectly. This approach is useful when program participation is optional or incentives do not ensure full compliance. In case of non-compliance, RDD estimates the intention-to-treat (ITT), providing a pragmatic assessment of the intervention's impact (Angrist and

Pischke, 2009; Hahn et al., 2001; Smith et al., 2017). In contrast, in a *sharp* RDD, treatment assignment is deterministic: all individuals on one side of the cutoff are treated, and none on the other side are, resulting in a clear shift in the probability of treatment.

In this context, although women are eligible for the NBCSP if aged 50-74, creating a cut-off in the women population, eligibility does not necessarily imply participation. Some eligible women might decline the screening offered by the public health system, leading to *imperfect compliance*. Consequently, the discontinuity in the probability of participating in the program at the official eligibility age is less than 100%. To address endogeneity from partial compliance, an *instrumental variable* estimation strategy is used, where the exogenous assignment to the treatment, *eligibility*, is treated as an instrument for *effective participation* in the screening program. The treatment status is determined as a discontinuous function of age.

A Two-Stage-Least-Squares model (2SLS) is applied to estimate a parametric equation, with the second stage estimation equation specified as follows:

$$Y_{ir}^{t} = \beta + \beta_1 \widehat{Effective\ Screening}_{ir}^{t} + \beta_2 f(age_{ir}^{t}) + \beta_3 \chi_{ir}^{t} + \gamma_r + \gamma_t + \epsilon_i \qquad (1)$$

The first stage estimation equation is formulated as:

$$Effective\ Screening_{ir}^{t} = \phi_0 + \phi_1 Eligibility_{ir}^{t} + \phi_2 g(age_{ir}^{t}) + \phi_3 \chi_{ir}^{t} + \gamma_r + \gamma_t + v_i \qquad (2)$$

Y_{ir}^{t} is the outcome variable, specifically breast cancer mortality rate for age group i in year t in region r. The variable *Effective Screening* measures the regional participation rate per age group i in year t in region r. $f(age_{ir}^{t})$ and $g(age_{ir}^{t})$ are flexible functional forms relating the forcing variable, *age*, to mortality rate and actual screening participation. χ_r^t, a vector of regional characteristics, is included to improve the precision and robustness of the estimates, although RDD does not require conditioning on baseline variables, as noted by Lee and Lemieux (2010). Regional and year-fixed effects, denoted by γ_r and γ_t, control for unobserved heterogeneity and any region- and time-specific characteristics that may influence the outcome variable. The error term, ϵ, captures unobserved factors affecting the mortality rate.

Equation 2 represents the first stage of the relationship between women's *effective participation* in the screening program and age eligibility, linking endogenous treatment variables to exogenous variables and instruments. The parameter ϕ_1 measures the effect of the assigned treatment, *Eligibility*, on the effective participation, *Effective Screening*. The *Effective Treatment* variable is instrumented with the *Assigned Treatment*, a dummy variable, taking a value of 1 for eligible women, aged 50-74, while 0 otherwise.

Equation 1 represents the relationship between mortality rate and NBCSP. Assuming continuity in the relationship between the outcome variable and age eligibility around the cut-off point and that treatment assignment is as good as random (Lee and Lemieux, 2010), any discontinuity in the dependent variable, Y_{ir}^t, near the cut-off point can be interpreted as evidence of a causal effect of the treatment (Hahn et al., 2001). The parameter β_1 measures the causal impact of national breast cancer screening on mortality. As in any standard IV framework, the estimated treatment effect is interpreted as the Local Average Treatment Effect (LATE) for those individuals who participate in the program due to their eligibility (*compliers*). Drawing on Gelman and Imbens (2019), the model is estimated using a linear polynomial of the running variable for the full sample and with different windows around the threshold. Higher-order polynomial models may generate imprecise estimates when the sample is small, as is the case here.

The main parametric analysis is complemented with a non-parametric approach using a Local Linear Regression to explore the sensitivity and robustness of the estimates (Hahn et al., 2001). The non-parametric RDD avoids assuming a specific functional form for age, constructing the predictor based on data-derived information (Jacob et al., 2012). One of the challenges is selecting an appropriate bandwidth. This choice must balance precision and bias. A larger bandwidth provides more precise estimates due to a larger number of observations but may introduce bias (Lee and Lemieux, 2010). To address this, a data-driven MSE-optimal bandwidth selector around the cut-off is employed, following Calonico et al. (2014) and Calonico et al. (2020). A *triangular kernel* is used to fit local linear regressions on each side of age 50 as it provides the best boundary correction method, assigning more weight to

observations near the cutoff and less to those further away (Cheng et al., 1997). Different kernel functions are used as robustness checks.

4.2 RDD validity test

The validity of the RDD strategy rests on several underlying assumptions. Before revealing the main findings, a series of tests are conducted to verify if these assumptions are satisfied. Graphical analyses are integral to any RDD to validate the credibility of the study (Imbens and Lemieux, 2008; Lee and Lemieux, 2010).

4.2.1 Discontinuity in the probability of exposure at the cut-off *(Treatment by forcing variable)*

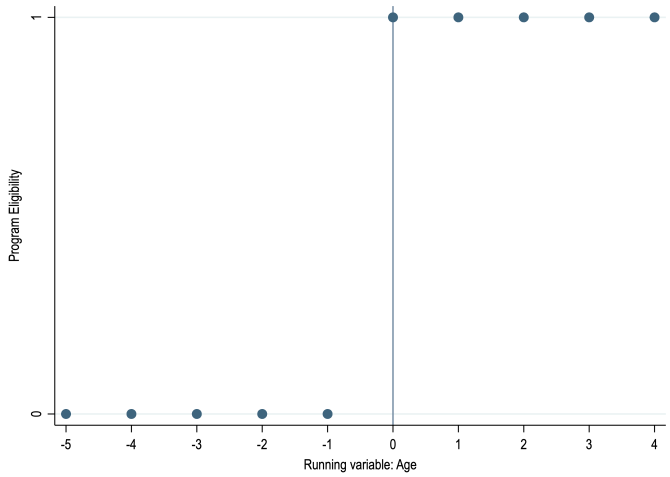
The RDD assumes a discontinuous change in the probability of exposure at the assignment cut-off, determined by the running variable. For population-based breast cancer screening, the eligibility cut-off is age 50. Women above 50 are eligible for the treatment, while those below are not. The first step is to verify the presence of a discontinuity in exposure in this study.

To evaluate this assumption, graphs of the probability of programme eligibility and breast cancer screening participation relative to the forcing variable are presented. Following standard RDD practices, the *forcing variable* (age) is centred around the threshold. This centring simplifies the interpretation of results and improves the precision of estimates of the average treatment effect around the cut-off point, with the intercept located at the cutoff point.

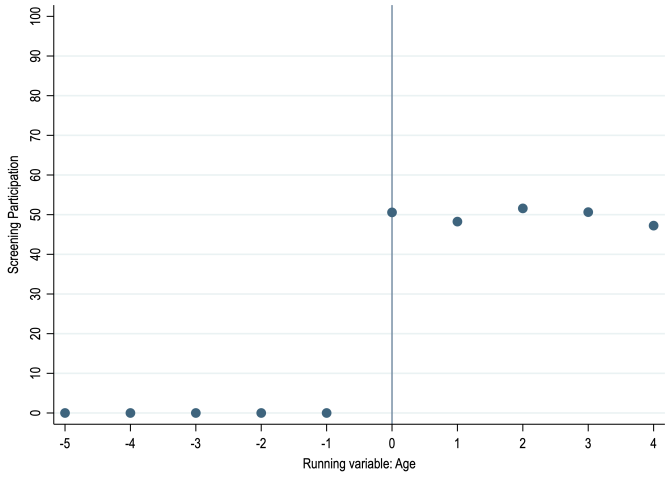
Figure 4 illustrates the variation in treatment probability as the forcing variable crosses the threshold. Figure 4a shows a deterministic relationship between programme eligibility and age, supporting the assumption for a sharp RDD, as treatment probability shifts from 0 to 1 around the cutoff. However, Figure 4b shows that program eligibility affects actual participation in the programme. Participation among eligible women ranges from 47% to 51% between 2005 and 2021, indicating that not all eligible women participated (*no-show*). This assumption is satisfied for the fuzzy RDD and probabilistic assignment.

Figure 4: Treatment by forcing variable

(a) Program Eligibility



(b) Effective Participation



Notes: Figure 4a shows changes in the probability of receiving treatment as the forcing variable crosses the threshold in a deterministic RDD, with a jump from 0 to 1. Figure 4b shows actual participation in the treatment based on eligibility, reporting mean regional participation rates, expressed in percentage, by age group from 2005 to 2021. Age is reported using the ID age group for data matching.

4.2.2 Lack of manipulation in the forcing variable (*Density of the forcing variable)*

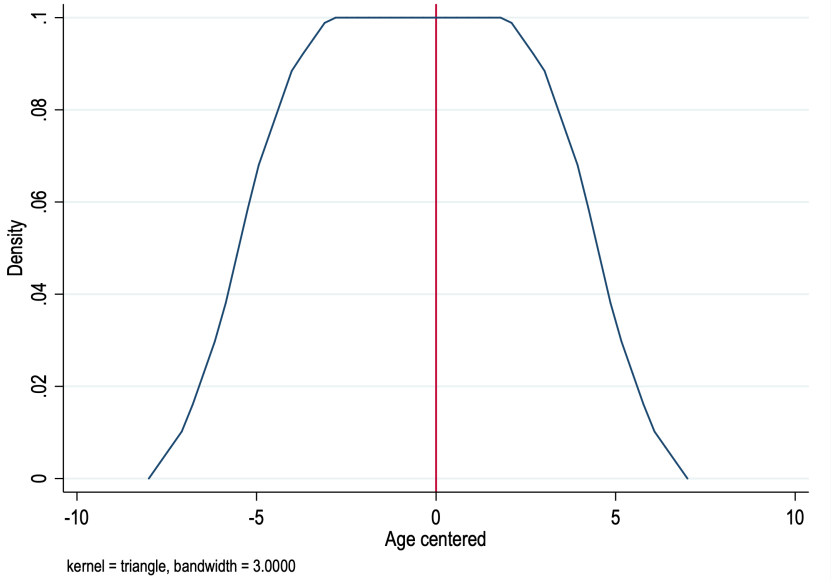
An important condition in the RDD is the absence of manipulation in the forcing variable. This ensures that assignment to the treatment or control group around the threshold is random. Any abrupt changes in the density of the forcing variable at the

threshold could indicate manipulation, which may suggest sorting and potentially invalidate the design. Smooth densities and lack of jumps at cutoffs are crucial for this condition (Imbens and Lemieux, 2008; Lee and Lemieux, 2010).

To validate local random assignment, the density of the forcing variable is examined around the cutoff point. In this study, age is the forcing variable, with eligibility criteria defined by the French government. This minimises the risk of individuals manipulating their age to influence inclusion or exclusion from the NBCSP. It seems unlikely that individuals can control the assignment variable.

Figure 5 shows the kernel density of the forcing variable with a bandwidth of 3, providing a visual check for signs of manipulation. The smooth and relatively flat density around the threshold indicates continuity in the density of the forcing variable, supporting the validity of the RDD approach used in this paper. Additionally, a formal manipulation test, proposed by McCrary (2008) was conducted, which tests the null hypothesis of continuity of the density of the variable against the alternative of a jump in the density function at the discontinuity point. The test found no significant evidence of a discontinuity in the distribution of age at the eligibility threshold. The absence of plausible manipulation provides strong evidence that the forcing variable has not been manipulated by individuals.

Figure 5: Density of the forcing variable



Notes: Figure 5 shows the distribution of the assignment variable, relative to the cutoff, to test for manipulation. The distribution is centred on the cutoff, representing the eligibility threshold for breast cancer screening.

4.2.3 Continuity of the outcome in the absence of any treatment *(Outcome by forcing variable)*

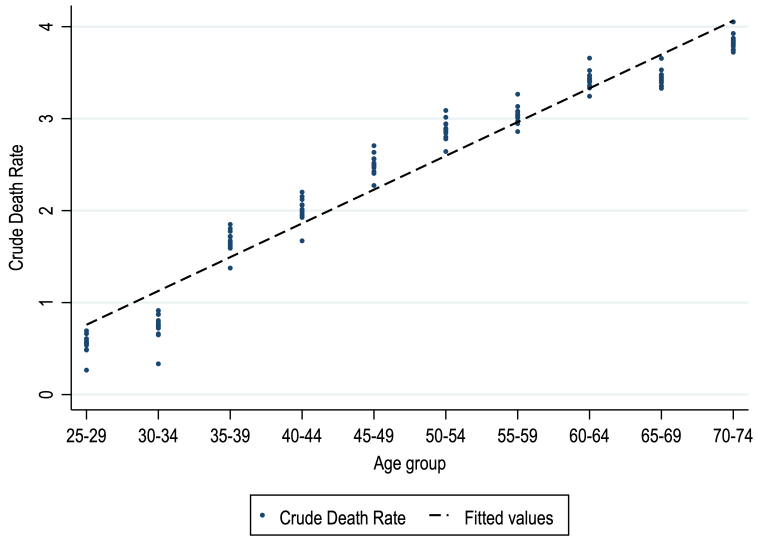
A third fundamental assumption is that, in the absence of the treatment, the outcome would have been continuous around the cut-off. This extends the exchangeability principle, meaning that any discontinuity in the outcome can be attributed to exposure alone. To assess this assumption, it would be necessary to observe the counterfactual outcome, namely breast cancer mortality rates in the same population and time period without the screening programme. Since this is not possible, it is sufficient to assess the outcome in plausibly exchangeable alternative populations or periods.

To assess continuity, Figure 6 presents the risk of *breast cancer mortality rate* for each value of the forcing variable, *age*, without considering the cut-off defined by eligibility. This helps determine if there is a smooth transition across the eligibility cut-off, and validate the assumption, particularly near the cut-off. Figure 6a shows the average mortality rate per age group and region, while Figure 6b only per age. As expected, breast cancer mortality increases with age, consistent with existing

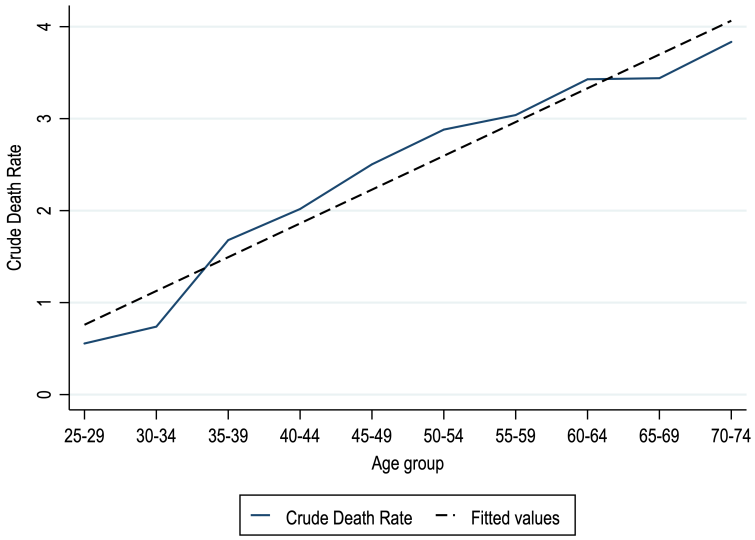
medical evidence. Breast cancer mortality rates rise steadily from around age 30-34 and more steeply from around age 65-69.

Figure 6: Breast cancer mortality by forcing age (2005-2021)

(a) Trend by age group and region



(b) Trend by age group

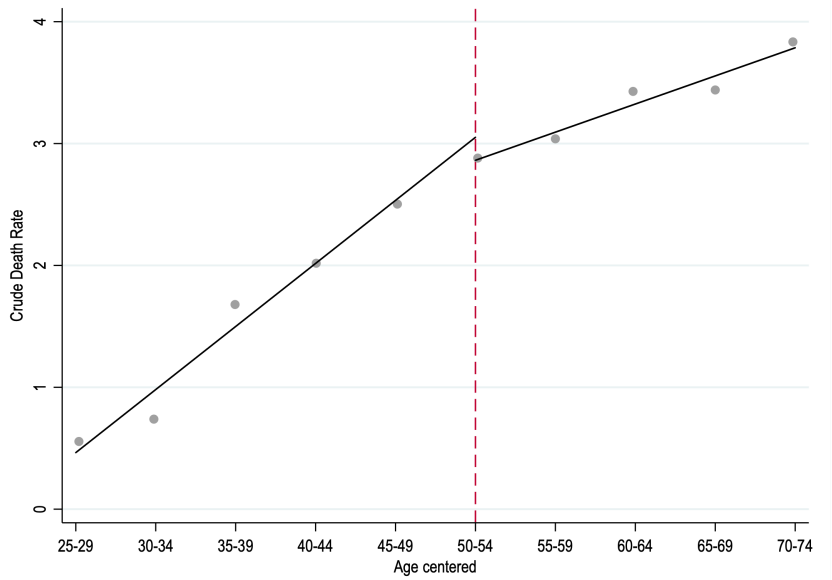


Notes: Graph 6a presents the trend in breast cancer mortality from 2005 to 2021, averaged by age group and region. Graph 6b shows the trend in breast cancer mortality over the same period, averaged by age group. Both graphs report the death rate in logs.

The graphical analysis of breast cancer mortality relative to the forcing variable is then presented by including the *screening eligibility* cut-off, at age 50, as shown in

Figure 7. This analysis helps identify any discontinuity at the cut-off, providing preliminary evidence for a causal effect (Imbens and Lemieux, 2008; Hagemeier et al., 2022). Discontinuity suggests a treatment effect, while continuity indicates minimal or no effect. Additionally, this analysis helps identify other discontinuities, which might indicate temporal trends or other influencing factors. Figure 7 shows a visible jump near the cutoff point (red dashed line), suggesting a treatment effect of the population-based screening program. This change in the death rate at the age cutoff provides preliminary evidence that the screening program impacts mortality among eligible women.

Figure 7: Discontinuity in treatment



Note: Graph 7 shows a visible jump near the cutoff point (red dashed line), indicating a discontinuity that suggests a treatment effect of the population-based screening program.

4.2.4 Continuity of the covariates at the cutoff (*Covariates by forcing variable*)

A last assumption for validating the RDD is the continuity of baseline observable characteristics that might potentially influence the outcomes of interest across the eligibility threshold. This involves comparing these characteristics just below and above the cut-off to ensure local balance. If treatment is locally randomised, there should be no significant differences in both observable and unobservable characteristics

around the eligibility cut-off.

The quasi-experimental nature of RDD implies that, aside from the exposure and outcome, all measured and unmeasured factors should be similar between groups. Baseline covariates such as regional GDP, GDP per capita, and the number of hospitals are determined before the assignment based on age. Any abrupt changes or discontinuities in these covariates at the threshold could suggest manipulation, which would undermine the assumption of local randomisation. As noted by Lee and Lemieux (2010), individuals who can manipulate the assignment might alter their pre-existing characteristics linked to the outcome.

To test for discontinuities, a simple *t-test* is employed to compare predetermined characteristics between groups just above and below the threshold, checking for equality of means. Table 2 presents the results of these tests. Most covariates show no significant difference between the treated and untreated groups, indicating continuity at the cutoff point, based on the coefficients and p-values. Socioeconomic variables and healthcare distribution appear balanced across the forcing variable, reinforcing the validity of the RDD analysis. However, *female population* variable shows a significant difference, as expected.

The absence of significant discontinuities in baseline covariates at the threshold provides strong evidence in support of the assumption of local random assignment. This suggests that the effect of the policy on mortality is primarily driven by the policy itself, rather than alterations in baseline characteristics. Overall, these validation checks strongly support the suitability of RDD as an identification strategy for drawing causal inferences.

Table 2: Differences in predetermined characteristics, *Controls* and *Treated*

	Not eligible		Eligible				
Variable	**Mean**	**St. Deviation**	**Mean**	**St. Deviation**	**Obs.**	***t-value***	***p-value***
GDP per capita	10.27	0.20	10.27	0.20	2208	0.0000	1.0000
Real GDP	11.64	0.94	11.64	0.94	2208	0.0000	1.0000
Hospitals	59.90	32.55	59.90	32.55	2208	0.0000	1.0000
Chemotherapy	33.33	20.28	33.33	20.28	2208	0.0000	1.0000
Radiotherapy	11.39	5.70	11.39	5.70	2208	0.0000	1.0000
Curietherapie	3.83	2.22	3.83	2.22	2208	0.0000	1.0000
Radioelements	5.48	3.38	5.48	3.38	2208	0.0000	1.0000
Breast Surgery	30.99	16.58	30.99	16.58	2208	0.0000	1.0000
Gynaecological surgery	23.96	12.23	23.96	12.23	2208	0.0000	1.0000
Female population	11.73	0.85	11.65	0.82	2208	2.2850	0.0224

Note: In Table 2, the continuity of the baseline characteristics is tested by investigating the equality of means of the treated and untreated group.

5 Results

5.1 Parametric fuzzy estimates

This section presents 2SLS estimates of the impact of the NBCSP on women's mortality. Effective participation in the programme is instrumented using assigned treatment, *eligibility*, after validating the RDD in Section 4.2.

Table 3 shows findings when the outcome variable is *breast cancer mortality* (expressed in logs). Parametric fuzzy RDD is employed on the full sample (Columns 1-2) and within a specific window (Columns 3-6). The analysis includes a first-order polynomial of the forcing variable and a linear interaction term between the treatment status and the assignment variable. Columns (1), (3) and (5) present baseline results without control variables, time, and regional fixed effects, while Columns (2), (4), and (6) include these controls to assess robustness. Standard errors are robust to heteroskedasticity in all specifications.

The findings contribute significantly to understanding the impact of population-based breast cancer screening on mortality. Table 3 (Panel B) reports first-stage estimates, showing a strong correlation between the assigned treatment, *Eligibility*, and effective

treatment, *Effective Participation*. Being assigned to the treatment around the threshold increases the probability of participating in the program, with coefficients ranging from 3.930 to 3.952 ($p < 0.01$). This effect remains consistent and robust across various model specifications, lending credibility to the observed relationship. The inclusion of the interaction term, $Eligibility \times Age_{centered}$, further refines understanding by estimating how the treatment effect varies with the running variable, *Age*. The interaction term shows some variability, indicating that the effect of eligibility on participation rate might be moderated by age, with coefficients ranging from -0.012 to 0.023, and varying significance across models. This finding, supported by Figure 4b and Figure 10, provides valuable insights for targeted policy interventions.

Table 3 (Panel A) reports second-stage estimates. The findings indicate a negative and statistically significant effect of the variable of interest, *Effective Participation*, on breast cancer mortality. This effect is consistent both for the full sample (coefficients from -0.048 to -0.049, $p < 0.01$) and within a narrower window of $\pm$ 2 (coefficients of -0.037 to -0.039, $p < 0.01$). However, the effect becomes negative but not significant beyond a certain range from the eligibility threshold, indicating that actual participation directly impacts the program's effectiveness in reducing breast cancer mortality. The benefits of participation decline as individuals move further away from the eligibility threshold. These findings emphasise the critical role of participation and engagement in a programme's effectiveness.

In Columns (2), (4), and (6), which include the full set of covariates, results indicate a slight increase in the probability of reducing mortality. By controlling for time and regional fixed effects and adding regional characteristics to account for potential confounding factors, the estimates remain stable in significance and magnitude. These controls increase the explanatory power of the models.

Among the control variables, the distribution of hospitals has a notable impact on mortality rates. A greater number of hospitals offering *Breast surgery* contributes to reducing mortality rates, with effects ranging from -0.026 to -0.030. On the contrary, positive and significant coefficients for hospitals offering *Radioelements*, ranging from 0.043 to 0.057 ($p < 0.05$), and *Gynaecological*, ranging from 0.030 to 0.032 ($p < 0.1$),

suggests that lower concentrations of these cancer care treatments may contribute to specialised treatments. A greater number of CRCDCs in the region significantly reduces mortality, likely due to improved organisation and management, with effects ranging from -0.390 to -0.585 ($p < 0.01$). Additionally, a negative and significant correlation between female population growth and mortality indicates that mortality rates decrease as population growth increases. Consistent with Yang et al. (2017), *GDP per capita* shows a positive correlation with mortality across specifications, although significant only for the full sample.

Finally, the models have high explanatory power, with R-squared values ranging from 0.844 to 0.962, indicating that the included variables explain a substantial proportion of the variance in breast cancer mortality. The robustness across different specifications reinforces the validity and reliability of the relationship. These results provide strong evidence of the impact of NBCSP in reducing mortality and offer a detailed understanding of the complex relationship between age, treatment assignment, and mortality outcomes.

Table 3: Fuzzy RDD estimates: Main results

	Linear (Full)		**Linear Window: ± 3**		**Linear Window: ± 2**	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel (a): 2SLS						
Effective participation	-0.048***	-0.049***	-0.001	-0.001	-0.037***	-0.039***
	(0.005)	(0.004)	(0.006)	(0.004)	(0.008)	(0.006)
$Age_{centered}$	0.517***	0.523***	0.412***	0.414***	0.486***	0.492***
	(0.005)	(0.005)	(0.010)	(0.008)	(0.021)	(0.017)
1.Eligibility x $Age_{centered}$	-0.287***	-0.306***	-0.205***	-0.214***	-0.212***	-0.233***
	(0.006)	(0.007)	(0.011)	(0.010)	(0.023)	(0.019)
Women Population (logs)		-0.125***		-0.072*		-0.271*
		(0.034)		(0.038)		(0.053)
GDP per capita		1.752**		0.938		0.413
		(0.856)		(0.923)		(1.044)
Regional Real GDP		-0.761		-0.432		-0.057
		(0.525)		(0.586)		(0.659)
Chemotherapy		0.002		0.003		0.002
		(0.009)		(0.009)		(0.009)
Radiotherapy		-0.009		-0.003		-0.005
		(0.006)		(0.005)		(0.005)
Brachytherapy		-0.002		-0.001		0.012
		(0.014)		(0.011)		(0.012)
Radioelements		0.057**		0.051**		0.043**
		(0.024)		(0.021)		(0.022)
Breast Surgery		-0.026*		-0.030**		-0.032**
		(0.015)		(0.014)		(0.014)
Gynecology Surgery		0.032*		0.031**		0.030**
		(0.016)		(0.016)		(0.016)
CRCDC		-0.585***		-0.484***		-0.390*
		(0.172)		(0.186)		(0.209)
Constant	3.051***	0.290	2.891***	3.280	2.989***	6.026*
	(0.015)	(3.083)	(0.020)	(3.026)	(0.029)	(3.298)
R-squared	0.951	0.962	0.899	0.935	0.844	0.911
Panel (b): First stage						
Assigned Treatment (*Eligibility*)	3.947***	3.952***	3.931***	3.933***	3.930***	3.935***
	(0.010)	(0.008)	(0.011)	(0.012)	(0.012)	(0.012)
Eligibility x $Age_{centered}$	-0.012***	0.012***	0.004	0.023***	0.007	0.024**
	(0.004)	(0.004)	(0.006)	(0.006)	(0.009)	(0.012)
R-squared	0.996	0.998	0.995	0.998	0.994	0.998
Polynomial Forcing Variable	First	First	First	First	First	First
Interaction term	Yes	Yes	Yes	Yes	Yes	Yes
Regional FE	No	Yes	No	Yes	No	Yes
Year FE	No	Yes	No	Yes	No	Yes
Covariates	No	Yes	No	Yes	No	Yes
Observations	2210	2210	1547	1547	1105	1105

Notes: Parametric Fuzzy RDD estimates. (a) In Panel (a), the outcome variable is *breast cancer death mortality*, expressed in logs. In Panel (b), the outcome variable is *Screening Participation*, expressed in logs. (b) Results are reported for linear parametric regressions using the full sample, columns (1-2), and around a window (3-6). (c) Columns (1), (3) and (5) are parametric estimates obtained without incorporating regional and time-fixed effects and baseline covariates. (d) Standard errors are robust to heteroskedasticity, as suggested by Imbens and Lemieux (2008). *** p<0.01, ** p<0.05, * p<0.1.

5.2 Intention-to-treat analysis

Since policymakers are interested in understanding the expected benefits of a programme, the Intention-To-Treat (ITT) effects are reported (Heckman et al., 1999). To derive the ITT estimates, a Sharp Regression Discontinuity Design (Sharp RDD) is implemented, where treatment status is simply defined by the assignment rule, *Eligibility* (Imbens and Lemieux, 2008; Angrist and Pischke, 2009). This empirical strategy corresponds to the reduced form of a 2SLS model, as shown in Equation 1 and Equation 2:

$$Y_{ir}^{t} = \beta_0 + \beta_1 Eligibility_{ir}^{t} + \beta_2 h(age_{ir}^{t}) + \beta_3 \chi_{ir}^{t} + \gamma_r + \gamma_t + \epsilon_i \tag{3}$$

Table 4 presents intention-to-treat (ITT) estimates using a Sharp RDD. Columns (1)-(6) report linear parametric regressions for the full sample and around windows of $\pm$ 3 and $\pm$ 2. The outcome variable is *breast cancer mortality rate*. After controlling for a linear polynomial of the assignment variable and a first-order interaction term between the treatment and forcing variable, the estimates indicate that assignment to the treatment, notably *screening eligibility*, leads to a reduction in the mortality rate between 0.147 and 0.280, with statistical significance at $p < 0.01$. These findings suggest that population-based screening could effectively reduce mortality. However, it is important to consider that some women might opt for *opportunistic screening*, which could potentially overestimate the true effect of the population-based screening. Nevertheless, the ITT effect remains quite robust and consistent with 2SLS estimates reported in Table 3, although slightly smaller in magnitude.

Table 4: Intention-to-treat

	Linear (Full)		**Linear Window: ± 3**		**Linear Window: ± 2**	
	(1)	(2)	(3)	(4)	(5)	(6)
Age centered	0.517***	0.524***	0.412***	0.414***	0.486***	0.492***
	(0.005)	(0.005)	(0.010)	(0.008)	(0.021)	(0.018)
1.Eligibility	-0.189***	-0.192***	-0.004	-0.005	-0.147***	-0.153***
	(0.018)	(0.015)	(0.022)	(0.017)	(0.031)	(0.023)
1.Eligibility x $\text{Age}_{centered}$	-0.287***	-0.306***	-0.205***	-0.214***	-0.212***	-0.234***
	(0.006)	(0.007)	(0.011)	(0.010)	(0.023)	(0.019)
Female population (logs)		-0.133***		-0.072*		-0.279***
		(0.034)		(0.038)		(0.054)
GDP per capita		1.741**		0.938		0.403
		(0.864)		(0.935)		(1.061)
Real GDP (Regional)		-0.753		-0.432		-0.052
		(0.531)		(0.593)		(0.670)
Chemotherapy		0.002		0.003		0.002
		(0.009)		(0.009)		(0.009)
Radiotherapy		-0.009		-0.003		-0.005
		(0.006)		(0.005)		(0.005)
Brachytherapy		-0.002		-0.001		0.013
		(0.014)		(0.011)		(0.012)
Radioelements		0.057**		0.051**		0.044*
		(0.024)		(0.021)		(0.023)
Breast Surgery		-0.025*		-0.030**		-0.031**
		(0.015)		(0.014)		(0.014)
Gynaecological Surgery		0.031*		0.031**		0.029*
		(0.017)		(0.016)		(0.017)
CRCDC		-0.586***		-0.484**		-0.390*
		(0.174)		(0.188)		(0.213)
Constant	3.051***	0.416	2.891***	3.284	2.989***	6.185*
	(0.015)	(3.134)	(0.020)	(3.068)	(0.029)	(3.377)
R-squared	0.951	0.962	0.899	0.935	0.846	0.911
Polynomial Forcing Variable	First	First	First	First	First	First
Interaction term	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	No	Yes	No	Yes	No	Yes
Year FE	No	Yes	No	Yes	No	Yes
Covariates	No	Yes	No	Yes	No	Yes
Observations	2210	2210	1547	1547	1105	1105

Notes: Sharp RDD estimates. (a) The outcome variable is *breast cancer mortality*, expressed in logs. (b) Results are reported for linear parametric regressions using the full sample, columns (1-2) and around a window (3-6). (c) Columns (1) and (2) are parametric estimates obtained without incorporating the baseline covariates. (d) Standard errors are robust to heteroskedasticity, as suggested by Imbens and Lemieux (2008). *** p<0.01, ** p<0.05, * p<0.1.

6 Quantification

Quantification is essential for policy analysis, democratic accountability, and effective governance. It forces policy-makers to confront trade-offs and evaluate alternatives systematically (Mesquita, 2024). By introducing rigour and precision, quantification shifts discussions from speculation about the impact of policies to measurable outcomes. It also sharpens debates and establishes clear standards of evidence by assessing the costs, benefits, and values of specific policies. In economic policy, the emphasis on quantification often leads to a preference for initiatives that yield measurable benefits over those with intangible advantages (Drechsler and Fuchs, 2023).

Building on this literature, and given the impact of the NBCSP in reducing mortality, I quantify the effect of the program on the observed mortality rate in this section. To do so, I base my evaluation on Equation 1 using the parameters estimated in Table 3, Column (6). The elasticity of *crude mortality rate* (M) with respect to *participation rate* (P) is denoted by β, and is estimated as:

$$\beta = \frac{\partial \ln M}{\partial \ln P} \simeq \frac{\Delta M/M}{\Delta P/P} = \frac{\Delta M}{\Delta P} \cdot \frac{P}{M} \tag{4}$$

where ΔM represents the change in the mortality rate, while ΔP represents the change in the participation rate. This relationship shows how a percentage change in the participation rate (P) affects the percentage change in the mortality rate (M). From this, it comes immediately that:

$$\hat{\Delta} M_r = \hat{\beta} \times \frac{M_r}{P_r} \times \Delta P_r \tag{5}$$

where $\hat{\Delta} M_r$ represents the estimated change in the mortality rate for region r. $\hat{\beta}$ is the estimated elasticity coefficient, quantifying the sensitivity of the mortality rate to changes in the participation rate. M_r is the observed mortality rate in region r. P_r is the observed participation rate in region r. ΔP_r is the change in the participation rate for region r. This estimated change in mortality rate ($\hat{\Delta} M_r$) is proportional to both the mortality rate and the participation rate in the specified region r, making

$\hat{\Delta}M_i$ specific to each region and year, which is an attractive feature of this analysis. Table 5 (Panel A) presents the year-over-year changes in mortality rates (ΔM) and the corresponding number of lives saved thanks to the NBCSP. Each year shows a decrease in mortality rates, reflecting the positive impact of the program. For example, in 2005, the program reduced mortality by 10.10 points, saving 16.86 lives. Over time, the number of lives saved gradually decreases, as the population's response to the program stabilises.

Table 5 (Panel B) provides region-specific data on the changes in mortality rates (ΔM) and the corresponding number of lives saved. Regions with greater populations, like Île-de-France, show more significant absolute reductions in mortality (-11.23) and higher numbers of lives saved (+44.78).

Overall, a total of 246.89 women's lives have been saved within the window ± 2. While saving nearly 250 lives is a remarkable achievement that reflects a positive outcome of the intervention, the question for policymakers is whether this impact is meaningful relative to the program's costs. However, quantifying the economic value of a life saved is a much more complex and ethical issue that extends beyond the scope of this quantification exercise.

Table 5: Change in mortality and lives saved by year and region

Panel A Mortality Changes by Year			**Panel B** Mortality Changes by Region		
Year	ΔM	**Lives Saved**	**Region**	ΔM	**Lives Saved**
2005	-10.10	16.86	Auvergne-Rhône-Alpes	-10.08	26.15
2006	-10.00	16.38	Bourgogne-Franche-Comté	-10.81	10.46
2007	-8.83	15.10	Bretagne	-10.97	11.95
2008	-9.05	15.12	Centre-Val de Loire	-12.05	10.59
2009	-9.16	15.34	Corse	-8.94	1.02
2010	-8.97	14.78	Grand Est	-11.32	22.17
2011	-8.11	13.88	Hauts-de-France	-13.98	28.11
2012	-8.64	14.24	Ile-de-France	-11.23	44.78
2013	-8.57	14.30	Normandie	-12.98	14.81
2014	-8.39	14.33	Nouvelle-Aquitaine	-11.37	23.20
2015	-8.13	13.90	Occitanie	-11.03	21.40
2016	-8.94	14.54	Pays de la Loire	-11.98	14.41
2017	-8.42	14.56	Provence-Alpes-Côte d'Azur	-10.32	17.83
2018	-8.27	14.13			
2019	-8.45	14.10			
2020	-7.96	13.41			
2021	-7.06	11.95			

7 Robustness checks

This section presents several robustness checks to assess the sensitivity of the results and confirm their reliability across different model specifications. Various analyses are conducted using non-parametric estimators, modifying key characteristics, such as kernel functions and bandwidth. The estimates are implemented using a non-parametric Triangular kernel. The analysis is repeated using an Epanechnikov kernel.

7.1 Non-parametric fuzzy estimates: Triangular kernel

The main findings are obtained through a parametric approach, which relies on arbitrarily chosen bandwidths or windows. However, parametric estimates might be inconsistent if the model is misspecified. To address this and assess the robustness of the parametric results, the Fuzzy RDD is also estimated non-parametrically. This approach allows for optimal bandwidth selection, focusing on data closer to the cut-off, thus minimising bias from data further away from the cutoff when estimating local treatment effects. Non-parametric methods require careful specification of the kernel function and the algorithm for selecting optimal bandwidths.

The non-parametric estimates are reported using a triangular kernel, a linear polynomial of the running variable, and a first-order interaction term between the treatment and the running variable, with robust standard errors. Literature indicates that triangular kernel is optimal for the point estimates at boundaries (Lee and Lemieux, 2010).

To obtain local polynomial RDD estimates with bias correction, robust inference and data-driven bandwidth selection, I refer to recent developments by Calonico et al. (2014). The bandwidths are selected using a symmetric mean squared error (MSE) optimal bandwidth, ensuring that equal bandwidths on both sides of the threshold. These optimal bandwidths are larger than the fixed bandwidths of $\pm$ 3 and $\pm$ 2 used in the parametric analysis, indicating a trade-off between higher variance and lower bias.

Table 6 presents the non-parametric Fuzzy RDD estimates using a Local Linear

Regression (LLR) approach, adjusting for a few mass points around the threshold. Columns (1), (3), and (5) show results without fixed effects, additional covariates, or interaction terms. Columns (2), (4), and (6) include the full set of covariates, fixed effects, and interaction terms. The point estimates exhibit similar patterns in both magnitude and statistical significance as the parametric estimates.

In Column (1), the non-parametric specification with the triangular kernel, without control variables, suggests that screening is associated with an approximate 0.047-0.048 point decrease ($p < 0.01$) in mortality. While this finding is slightly lower than the parametric estimates, it remains statistically significant. Both parametric and non-parametric estimates consistently support the conclusion that population-based breast cancer screening significantly reduces mortality compared to non-screened women, with effectiveness dependent on actual participation.

The choice of bandwidth is critical in non-parametric models. To ensure robustness across different model specifications, additional sensitivity analyses are conducted using various window sizes around the eligibility cutoff. Results remain robust across a range of bandwidths. These analyses confirm that the results are not driven by distant data points from the discontinuity (Angrist and Pischke, 2009; Lee and Lemieux, 2010). The non-parametric results align with the baseline findings, retaining significance and magnitude comparable to those from the parametric Fuzzy RDD (see Tables 3 and 4). This consistency reaffirms the robustness of the findings across different bandwidth specifications.

Table 6: Non-parametric estimates - Triangular kernel

	Optimal Bandwidth		**Bandwidth ±3**		**Bandwidth ±2**	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel (a): 2SLS						
RDD_Estimate	-0.047***	-0.048***	-0.011**	-0.013***	-0.033***	-0.037***
	(0.005)	(0.004)	(0.005)	(0.004)	(0.008)	(0.006)
Panel (b): First stage						
Effective treatment	3.939***	3.942***	3.934***	3.936***	3.936***	3.939***
N left	884	884	663	663	442	442
N right	1105	1105	884	884	663	663
Bandwidth	MSE	MSE	4	4	3	3
Region FE	No	Yes	No	Yes	No	Yes
Year FE	No	Yes	No	Yes	No	Yes
Covariates	No	Yes	No	Yes	No	Yes
Polynomial	1	1	1	1	1	1
Interaction term	No	Yes	No	Yes	No	Yes

Notes: Fuzzy RDD estimates within the MSE-optimal bandwidth and alternative bandwidth. The non-parametric estimates are obtained from triangular kernel regressions. (a) The dependent variable is *breast cancer mortality*, expressed in logs. (b) In all specifications, the model controls for a first-order polynomial of the assignment variable, and a first-order interaction term between the treatment and the running variable. (c) Standard errors are robust to heteroskedasticity. *** p<0.01, ** p<0.05, * p<0.1.

7.2 Alternative kernel function: Epanechnikov

This section presents additional robustness checks for the RDD estimation by using the Epanechnikov kernel with its optimal bandwidth, addressing the sensitivity of results to functional form and kernel functions. While the triangular kernel is optimal for non-parametric estimates at the boundary, the Epanechnikov kernel minimises bias by giving less weight to observations farther from the cutoff point, thereby reducing the influence of extreme data points.

Table 7 reports the non-parametric estimates using the Epanechnikov kernel. The first stage coefficient estimate is around 3.93-3.94 points ($p < 0.01$), indicating a strong relationship between the running variable and participation. The 2LS estimates show that screening is associated with an approximate 0.011-0.052 point decrease ($p < 0.01$) in breast cancer mortality. These RDD estimates remain significant and similar in magnitude to those obtained using the triangular kernel (see Table 6), showing a slightly stronger effect with the optimal bandwidth. These robustness checks confirm that the findings are consistent across different kernel functions and

bandwidths. The observed effect of breast cancer screening on mortality is stable and credible across various non-parametric estimations. Population-based breast cancer screening, conditional on participation, significantly reduces mortality.

Table 7: Non-parametric estimates - Epanechnikov kernel

	Optimal Bandwidth		**Bandwidth ±3**		**Bandwidth ±2**	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel (a): 2SLS						
RD Estimate	-0.052***	-0.053***	-0.011**	-0.013***	-0.036***	-0.039***
	(0.005)	(0.004)	(0.005)	(0.004)	(0.008)	(0.006)
Panel (b): First stage						
Effective treatment	3.941***	3.943***	3.932***	3.933***	3.933***	3.936***
	(0.010)	(0.010)	(0.011)	(0.012)	(0.012)	(0.016)
N left	884	884	663	663	442	442
N right	1105	1105	884	884	663	663
Bandwidth	MSE	MSE	4	4	3	3
Region FE	No	Yes	No	Yes	No	Yes
Year FE	No	Yes	No	Yes	No	Yes
Covariates	No	Yes	No	Yes	No	Yes
Polynomial	1	1	1	1	1	1
Interaction term	No	Yes	No	Yes	No	Yes

Notes: Fuzzy RDD estimates within the MSE-optimal bandwidth and alternative bandwidth. The non-parametric estimates are obtained from Epanechnikov kernel regressions. (a) The dependent variable is *breast cancer mortality*, expressed in logs. (b) In all specifications, the model controls for a first-order polynomial of the assignment variable, and a first-order interaction term between the treatment and the running variable. (c) Standard errors are robust to heteroskedasticity. *** p<0.01, ** p<0.05, * p<0.1.

8 Conclusion

This paper evaluates the impact of French population-based breast cancer screening programme, launched in 2004 for women aged 50 to 74, on mortality in the context of sub-optimal participation rates. Using a balanced panel from 2005 to 2021, covering 13 French regions and women aged 25-74, the study combines regional mortality data from CépiDc with regional screening participation rates from Santé Publique, socio-economic and structural covariates from Insee, and data on cancer treatment facilities, and Regional Cancer Screening Coordination Centres (CRCDCs) from the Institut National du Cancer. The analysis reveals significant disparities in mortality and participation across regions and age groups, alongside an uneven distribution of cancer care facilities.

A Regression Discontinuity Design (RDD) was implemented to assess the impact of the treatment, comparing mortality rates of women just above and below the age-eligibility threshold. Because participation is voluntary and shaped by individual preferences, not all eligible women participate in the program, leading to partial compliance with the treatment assignment. To address this, a Fuzzy Design was used instrumenting *effective participation* on *eligibility*.

Findings indicate that population-based screening significantly reduces mortality, though sub-optimal participation reduces its impact to about half of the intent-to-treat effect. The presence of hospitals offering breast cancer surgery and CRCDCs contributes significantly to lowering mortality. Results are robust across multiple robustness checks, including alternative control specifications, non-parametric approaches, and variations in bandwidths and kernel functions. Quantifying the programme's impact suggests that approximately 250 women's lives have been saved since its implementation.

While these findings spotlight the significant benefits of population-based screening as a justifiable and effective public health policy, they also raise important considerations for policymakers regarding the value of lives saved relative to the programme's costs. Policy-makers must weigh the benefits of mortality reduction against the financial, logistical, and social costs of implementing and maintaining such programmes. However, determining whether these benefits justify continuation goes beyond the scope of this study. A comprehensive cost-effectiveness analysis would need to account not only for financial and medical costs but also for the sensitive consideration of the socio-economic value of human life. This highlights the complexity inherent in evaluating public health interventions, where measurable impacts on mortality must be considered alongside economic and ethical implications.

From a broader perspective, this study contributes to public health policy evaluation by providing robust, causally identified estimates of the effect of screening on mortality at the recommended age threshold. It emphasises the importance of both eligibility and participation rates in determining programme effectiveness and informs debates on potentially extending the eligibility age to women aged 40–45.

These results have several important policy implications. First, policymakers should

prioritise efforts to maximise participation by addressing socio-economic barriers, which can delay detection and treatment. While organised screening ensures equal delivery, it does not guarantee equal uptake. Higher participation yields substantial returns through earlier interventions, lower mortality, reduced healthcare costs, and decreased overall cancer burden. Geographic disparities in mortality and participation further highlight the need to improve access to care. Previous studies show that general practitioners and mobile screening units are effective tools for increasing participation, especially in remote areas (Pivot et al., 2011; Guillaume et al., 2017). Second, health authorities should strive for equitable distribution of cancer care resources. Partial or total absence of oncology-specific facilities in certain areas undermines equality in healthcare access and reduces the effectiveness of population-based screening.

Third, given the rising incidence of breast cancer among women aged 40–49, lowering the screening threshold could improve early detection, survival rates, and reduce treatment costs. Organisations such as the European Council and the U.S. Preventive Services Task Force advocate lowering the starting age to 40–45 while retaining the upper limit of 74. Evidence from women around the eligibility threshold illustrates the benefits of such population-based screening on mortality. Given the controversy surrounding the appropriate age to start screening, decisions to extend the program should balance resource allocation, risk-benefit ratio, and factors beyond mortality reduction alone.

There are numerous opportunities for further research on this topic. Difference-in-Differences approaches could compare mortality outcomes for women aged 50–74 before and after programme implementation, addressing a limitation of the RDD, which estimates the Local Average Treatment Effect (LATE) near the eligibility threshold but not the Average Treatment Effect (ATE) for the broader population (Imbens and Lemieux, 2008). Analyses could also extend to women above 74 using RDDs with multiple thresholds. Finally, improving data tracking and collection on mortality rates, screening registration, and health indicators is another priority. While the NBCSP database from Santé Publique provides regional and departmental participation rates, no comprehensive database captures opportunistic

screening. Fragmented data from health insurance and the Senolog database, which do not distinguish between opportunistic, diagnostic, and follow-up mammograms, complicate evaluations of population-based screening's impact, as also noted by Quintin et al. (2022). Self-reported surveys or GP records, subject to selection biases, provide only approximate estimates of individual screening relative to organised screening (Ouédraogo et al., 2014). The lack of specific coding for opportunistic screening practices, covering participation, intervals, and detection, may overstate the NBCSP's effect on mortality.

Recent improvements include Data Pathologies reporting on reimbursed expenses, patient counts, and incidence by pathology, though data are available only from 2015–2021. Further improvements in registration and coding of screening procedures are needed for a more comprehensive assessment. The French Public and Scientific Consultation on Breast Cancer Screening highlights the importance of standardising screening conditions (Institut National du Cancer, 2016). Incorporating opportunistic screening into performance indicators, as recommended by European scientific societies, could improve monitoring of women not participating in the NBCSP (Muratov et al., 2020).

In conclusion, this work supports the effectiveness of population-based breast cancer screening in reducing mortality and highlights the need for targeted interventions to increase participation, improve data quality, and more accurately evaluate the impact of organised screening on breast cancer outcomes in France.

Declaration of competing interest

The author declares that she has no relevant or material financial interests that relate to the research described in this paper.

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Appendix

A French cancer plans

In 2003, the European Commission recommended population-based screening for women aged 50 to 69. In response, France has centred its cancer prevention efforts around three national cancer plans and a ten-year cancer control strategy. These initiatives aim to reduce delayed diagnoses and improve cancer treatment and survival rates through regular screening and early detection (INCa, 2003; INCa, 2009; INCa, 2015). The Ministry of Health has mobilised public health actors to encourage prevention, screening, research, and patient support, establishing a comprehensive network of cancer-care organisations. Key objectives of these plans are outlined in Table 8.

These plans have significantly impacted the healthcare system (Bousquet et al., 2018). They established national screening for breast, colon, and cervical cancers, promoted prevention in general and targeted populations, and reinforced care pathways. Major initiatives include authorising cancer care, training multidisciplinary teams, standardising documents to improve coordination, developing specific care pathways for rare cancers, and improving supportive care and quality of life during and after treatment. Despite improvements in survival rates due to medical and therapeutic innovations, as well as public health policies, breast cancer remains high. The rise in new cases reflects the ageing and growth of the French population.

Table 8: Historical evolution of cancer plans in France

Cancer Plan	Objectives
Plan Cancer 2003-2007	- By January 1, 2004, implement a nationwide breast cancer screening and early detection strategy for women aged 50 to 74, aiming for 80% coverage - Set minimum quality standards for cancer care in healthcare facilities (surgery, radiotherapy, chemotherapy) - Launch a new dynamic in cancer research by establishing seven cancer research centres (*cancéropôles*) - Create Regional Cancer Screening Coordination Centres (CRCDCs) to ensure efficient screening coordination - Set up the National Cancer Institute (INCa) to coordinate national cancer control
Plan Cancer 2009-2013	- Improve prevention strategies through targeted interventions and public awareness campaigns - Promote research and treatment innovations, focusing on advancing research in cancer genomics - Reinforce support systems for cancer patients and survivors - Consolidate the CRCDCs for optimal coordination and resource allocation - Address health inequalities to ensure equitable access to prevention - Implement personalised care by analysing individual and environmental factors - Improve the quality and safety of cancer care nationwide - Reinforce coordination between hospital teams and primary care providers
Plan Cancer 2014-2019	- Improve cancer treatment through multidisciplinary care approaches - Improve quality of life for cancer patients - Increase access to innovative treatments and therapies - Ensure equitable access to cancer screening services by improving CRCDC's coordination - Support and adopt new technology and treatments to improve cancer care standards - Reduce cancer mortality rates and treatment burdens through targeted interventions - Guarantee the quality and safety of breast cancer care services
Plan Cancer 2021-2030	- Prioritise personalised medicine to tailor breast cancer treatment to individual patients' needs - Improve prevention and breast cancer screening programs - Address health disparities to ensure equitable access to treatment - Implement prevention efforts in schools to raise awareness and encourage healthy behaviours - Improve access to breast cancer screening services to ensure early detection and timely intervention - Invest in research, education, and infrastructure to improve breast cancer survival and patient care - Promote higher survival rates and better quality of life for breast cancer patients

Note: Table 8 summarises the main objectives defined by the cancer plans and strategy adopted by France over the years.

B Summary statistics

Table 9: Summary statistics, *Full sample*

Variable	Obs.	Mean	Std. Dev.	Min	Max
Crude Death Rate	2210	2.412	1.102	0	4.239
Participation Rate	2210	1.962	1.967	0	4.236
Female Population	2210	11.689	0.836	8.926	13.078
GDP per capita	2210	10.271	0.200	9.944	11.037
Regional Real GDP	2210	11.638	0.943	8.827	13.496
Chemotherapy	2210	33.335	20.272	3	85
Radiotherapy	2210	11.389	5.695	2	26
Brachytherapy	2210	3.833	2.216	0	10
Radio-element	2210	5.480	3.384	0	13
Breast Surgery	2210	30.991	16.575	2	68
Gynaecological surgery	2210	23.959	12.224	2	47
CRCDC	2210	6.407	3.533	0	13

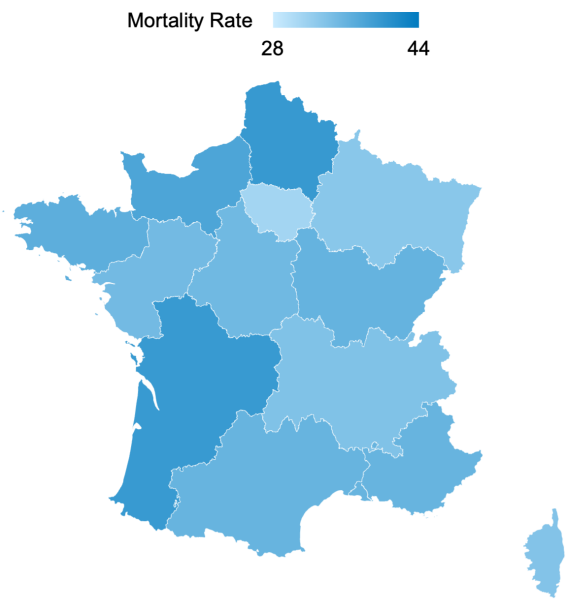
Table 10: Summary statistics, *Ineligible* vs *Eligible*

	Ineligible			Eligible		
Variable	**Obs.**	**Mean**	**Std. Dev.**	**Obs.**	**Mean**	**Std. Dev.**
Crude Death Rate	1105	1.499	0.788	1105	3.324	0.377
Participation Rate	1105	0.000	0.000	1105	3.924	0.183
Female Population	1105	11.729	0.850	1105	11.648	0.821
GDP per capita	1105	10.271	0.200	1105	10.271	0.200
Regional Real GDP	1105	11.638	0.944	1105	11.638	0.944
Chemotherapy	1105	33.335	20.276	1105	33.335	20.276
Radiotherapy	1105	11.389	5.696	1105	11.389	5.696
Brachytherapy	1105	3.833	2.217	1105	3.833	2.217
Radio-element	1105	5.480	3.384	1105	5.480	3.384
Breast Surgery	1105	30.991	16.578	1105	30.991	16.57
Gynaecological surgery	1105	23.959	12.227	1105	23.959	12.227
CRCDC	1105	6.407	3.534	1105	6.407	3.534

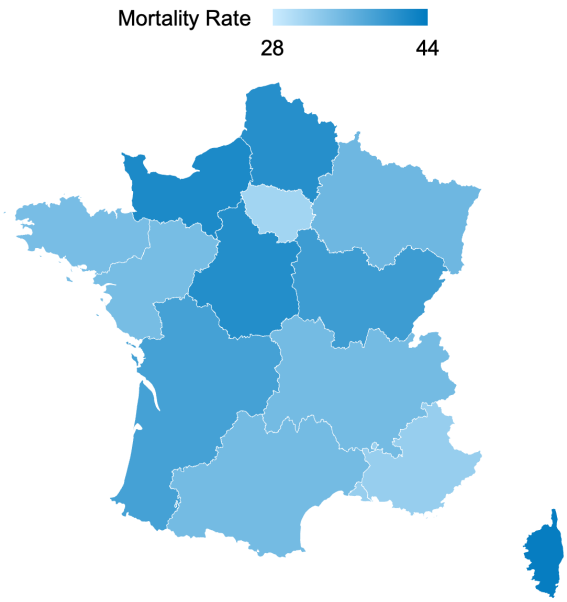
C Regional breast cancer death

Figure 8: Metropolitan France

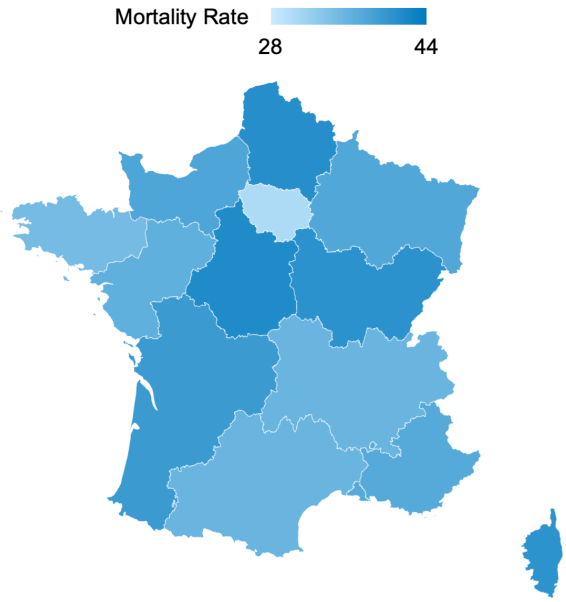
(a) France (2005)



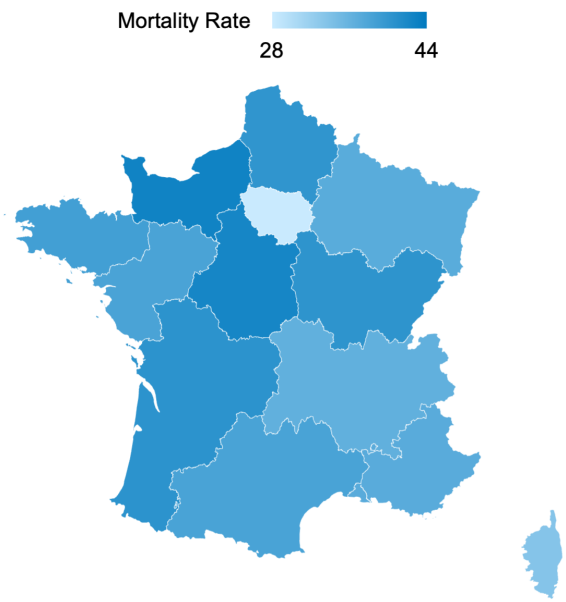
(b) France (2010)



(c) France (2015)



(d) France (2020)

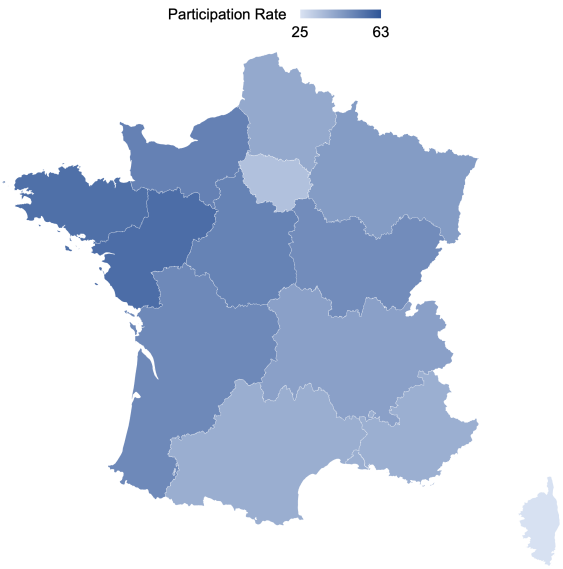


Notes: Author's analysis based on CépiDc data. Figure 8 shows breast cancer mortality rates at the regional level for metropolitan France, presented in five-year intervals.

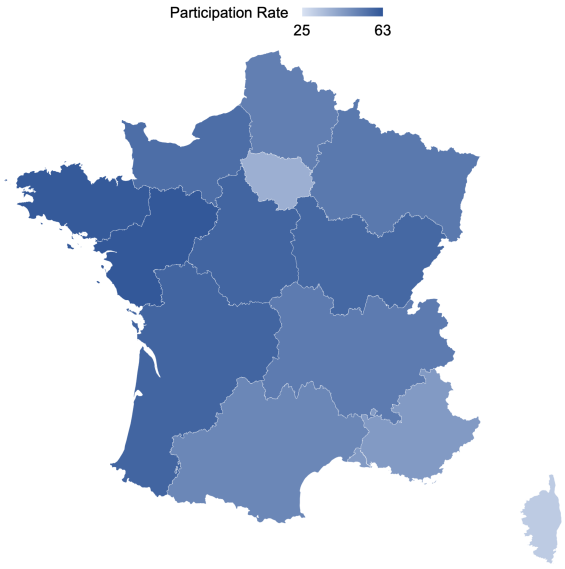
D Regional breast cancer participation

Figure 9: Metropolitan France

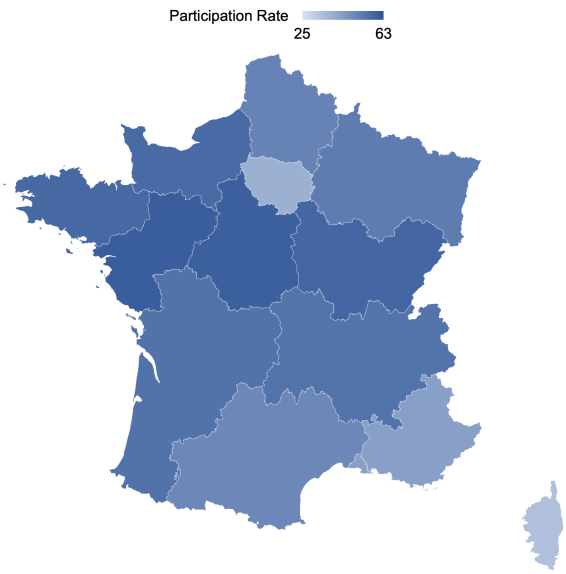
(a) France (2005)



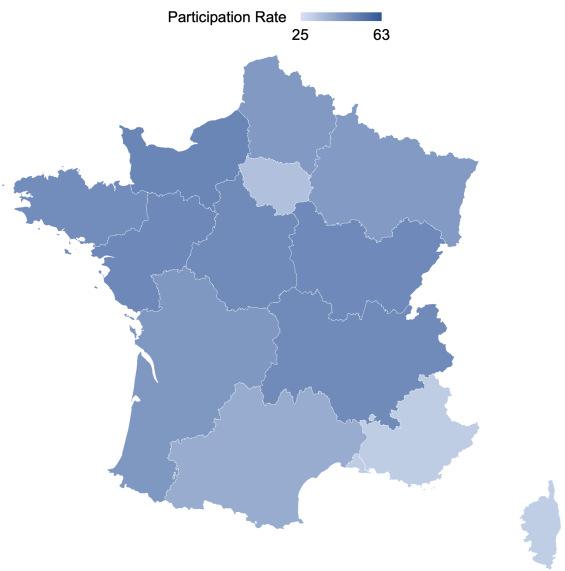
(b) France (2010)



(c) France (2015)



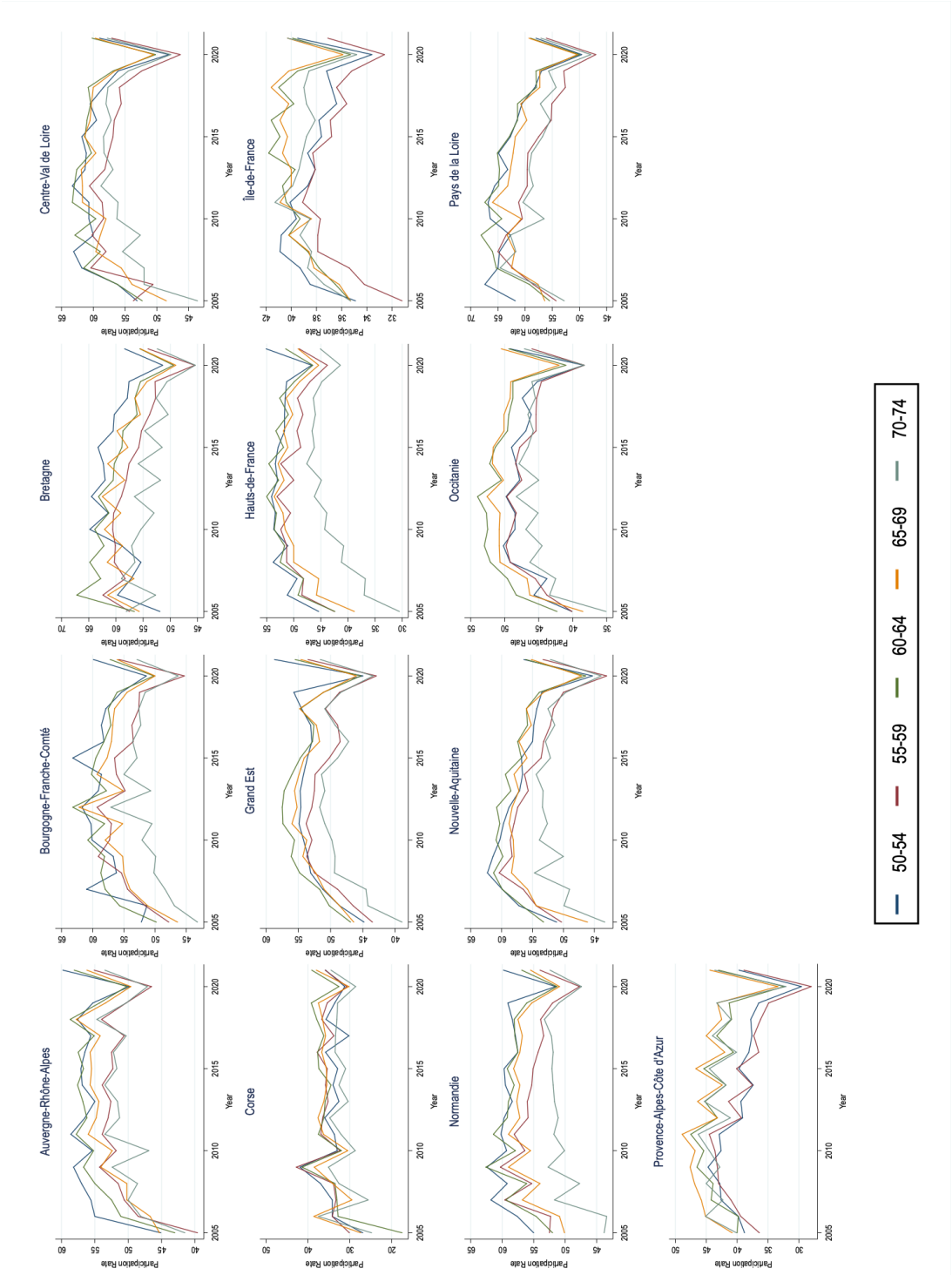
(d) France (2020)



Notes: Author's realisation based on aggregated data provided by Santé Publique. Figure 9 shows the participation rate in breast cancer screening, expressed as a percentage of women attending, at the regional level for Metropolitan France, over five years.

E Regional screening participation by age

Figure 10: Cancer screening participation by age



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