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Abstract

Background: Digital mammography saw rapid adoption during the first decade of the 2000s. We were interested in identifying the times and locations where the technology was introduced within the state of New York as a way of illustrating the uneven introduction of this technology.

Methods: Using a sample of Medicare claims data from the period 2004-2012 from women aged 65 and over without cancer, we calculated the percentage of mammograms which were digital by zip code of residence and illustrated these with a series of smoothed maps.

Results: Maps for three of the years (2005, 2008, and 2011) show the conversion from almost no digital mammography to nearly all digital mammography. The 2008 map reveals sharp disparities between areas which had and had not yet adopted the technology. Socioeconomic differences explain some of this pattern.

Conclusions: Geographic disparities in access to medical technology is underappreciated relative to other sources of disparities. Our method provides a way of measuring and communicating this phenomenon.

Impact: Our method could be applied to illuminate current examples where access to medical technology is highly uneven, such as 3-d tomography and robotic surgery.

Introduction

Full-field digital mammography (hereafter, "digital mammography") is a mammography system where solid state detectors are used to convert x-rays into electric signals which can then be translated into images viewable on a computer screen. Digital mammography was widely adopted in the United States during the first decade of the century, replacing a process which captured the images on photographic film. According to data maintained by the Food and Drug Administration, which regulates mammography equipment, fewer than 1 percent of the machines in 2001 were digital. By 2014, this figure had risen to 94% (1).

The efficiencies of digital mammography were immediately evident, even as it was unclear whether there were any diagnostic advantages. First, the images were immediately available, meaning that images that were blurry or otherwise flawed could be immediately retaken while the patient was still in the office, reducing the need for a return visit. This was an especially attractive feature in rural areas where travel is a burden. Second, digital images could be obtained more quickly on average, making for shorter office visits, of benefit to both patients and providers. Third, the digital images could be manipulated more easily to extract information, through magnification and adjustment of brightness and contrast. Fourth, digital images were easy to store, retrieve, and transmit. Secure electronic file-transfer protocols took the place of paid couriers hand-delivering films between offices. Fifth, digital imagery lent itself to the use of computer-aided detection (CAD) algorithms to call attention to features that human interpreters might have missed. Each of these advantages became even more pronounced over time as processing speeds, storage capacity, and image quality saw rapid improvements. Finally, there were also some environmental advantages, as the new machines reduced the average amount of personal radiation exposure by more than 20% (2), and eliminated the need for film-processing chemicals.

Still, a more important question was whether digital mammography was able to detect breast cancer accurately, or at least as accurately, as film-based methods. This question became the focus of numerous studies, ten of which were assessed in a 2013 meta-analysis (3). The analysis concluded that digital mammography was more accurate only in women less than 50 years old, which represents about 20% of all breast cancer diagnoses (or 15%, if one limits to women 40-49, since women under 40 are seldom screened for breast cancer). This is because younger women are more likely to have radiographically dense breasts, and digital mammography performs better for these women given the ability to manipulate the contrast of the image (4). The meta-analysis also showed that diagnostic accuracy improved over time, both for women under 50 and all women, which is consistent with technological improvements in digital image quality and detail over the decade.

All of these factors had to be balanced against the costs of conversion to digital mammography, which included the initial cost of the equipment, staff training, and, in some instances, more staff time required to interpret the images. Medicare began offering higher reimbursements for mammography in 2001, but other insurers were much slower to cover this procedure. Studies attempting to assess the ultimate cost-effectiveness of digital mammography have shown inconsistent results (5-7); certainly the early adopters of digital mammography faced considerable economic uncertainty when they made the decision to switch.

On the other hand, parallel trends in the broader film industry made the transformation to digital mammography an inevitable one. Global sales of film rolls for personal hand-held cameras peaked in 2000 at about 950 million, but had plummeted more than 90 percent by 2010 (8). The first commercial digital movie projectors in the U.S. were demonstrated in 1998, and by 2014, over 90 percent of U.S. movie screens had switched to digital projection (9). Eastman Kodak, the company most closely associated with film in the United States since the 1880s, went from its all-time peak in profits in 1999 to bankruptcy by 2012 (10). Without this broader infrastructure in place, the maintenance of film-based mammography was not practical.

Digital mammography thus offered greater convenience to both patients and practitioners, was more diagnostically accurate for a minority of the women screened and neutral otherwise, and was part of a massive shift away from film usage generally, even while incurring some financial risks. While the shift can be seen as inevitable, it was nevertheless uneven in space and time. We were interested in how this uneven diffusion might be measured and visualized. There is a well-developed literature on the diffusion of medical technology and innovation (11-16), but we are unaware of any studies which have attempted to map the diffusion process at a fine geographic scale. Indeed, diffusion is most often measured between countries. Synthesizing this literature, we can say that high-tech and high-cost innovations such as digital imaging tend to be first seen in larger, more affluent markets, particularly those with teaching hospitals. In contrast, rural and inner-city locations are typically among the last to see such innovations. This pattern results in a recurring cycle of temporary disparities between these types of places, which suggests that improving health care for all may be a more easily attainable goal than reducing disparities between groups. Our aim was to use maps to assess the extent to which New York State fit this pattern during the rapid transition from film-based to digital mammography.

Materials and Methods

We obtained Medicare claims data from a 5% sample of women aged 65 and over without cancer residing in New York State during the period 2004-2012, as part of New York State's recent participation in the SEER-Medicare linkage (17). A total of 136,637 diagnostic and screening mammograms were identified and classified as either film-screen (CPT/HCPCS codes 76090, 76091, 76092, 77055, 77056, and 77057) or digital (code G0202, G0204, and G0206). We then calculated the proportion of screening mammograms which were digital for every 12-month period between January 2004 and December 2012 by zip code. Zip code was finest spatial resolution available in the Medicare data; we did not have access to individual addresses. We then constructed a series of smoothed maps of the percentage of mammograms which were digital, as follows: first, a 2.5 kilometer resolution grid was created for New York State. Each grid cell was assigned the mammogram data from the nearest zip code, based on the distance between the grid cell centroids and zip code delivery area centroids. If the total number of mammograms in the nearest zip code was less than 50, then the mammogram data from the next closest zip code were added. This process was repeated until at least 50 mammograms were captured. This is the method described by Talbot et al. (18). Each cell was then shaded based on the percentage of mammograms that were digital, in 10% increments. Separate maps were generated for each twelve-month period in the data, for a total of 97 maps. The data smoothing and map generation were performed using R version 3.3.1. To highlight the socioeconomic disparities suggested by the maps, we also measured digital mammography by median household income deciles using data from the American Community Survey 2007-2011 estimates (19).

Results

Maps for three of the years - 2005, 2008, and 2011 - are presented in Figure 1. The 2005 map contains a large eye-catching area in the east-central portion of the state with close to 100% digital mammography, even as substantial portions of the state remained at or near zero. This area corresponds to the area surrounding the small city of Gloversville; its lone hospital was the first to adopt digital mammography in the state, in 2002. A handful of other areas of the state were at or near 50% in 2005, meaning that their digital services were first offered during the year, or competing providers in the same location were offering both kinds of mammography. By 2008, the year of the maximum income-based disparity, the map contains many distinct patches where film and digital mammography were in use. In general, more affluent locations were more likely to have adopted digital mammography by this point, as seen in the contrast between Brooklyn and Staten Island, where the median household income of the latter is 63% higher (19). Other patterns were less predictable, as seen in the contrast between Binghamton and Elmira, which are demographically similar. By 2011, there were just two places in the state where digital mammography was not in wide use: Jamestown and Buffalo, particularly inner-city Buffalo.

The complete set of 97 maps is available online as both a collection of individual files and as an animated .gif file (20).

The wealth disparity in the receipt of digital mammography is illustrated in graph form in Figure 2. The difference was modest in 2004-2005, when between 20% and 30% of the wealthiest women received a digital mammogram compared with 10% to 20% of the poorest. By 2008, the disparity had reached a maximum, with over 70% of the wealthiest women receiving a digital mammogram versus just half of the poorest women. By 2012, the disparity had been reduced considerably, with 95% of the wealthiest women and about 90% of the poorest women receiving a digital mammogram. In 2016, given that all licensed machines in the state of New York are digital, we can assume that the figure is essentially 100% for all women, regardless of income.

Discussion

Our results suggest that affluent areas were more likely to be among the early adopters of digital mammography, but that there were plenty of local exceptions to this pattern. The most notable of these was seen in the 160-bed hospital in Gloversville, a place well removed from major medical schools, universities, international airports, and other conventional markers of an innovation hub. Berwick (21) found that the existence of a local culture of support and investment in innovation and freedom to explore can sometimes overcome these shortcomings, and this may explain some of these local exceptions.

Technology is an underappreciated contributor to health disparities. Recent literature has tended to focus on geographic distance to health care providers, patterns of health insurance, behaviors of health care providers, or demographic differences in patient populations (22). There have been comparatively fewer studies highlighting the ways in which people may receive different care based simply on local differences in the availability and sophistication of medical equipment. These differences are often invisible to the patients, who tend to seek health care for reasons other than the presence of the latest technology. We specifically highlighted how these differences end up correlating with socioeconomic disparities in the population (23-25); a comparable analysis could have been done for race/ethnicity, rurality, proximity to medical schools, or any other variable of interest.

In the case of digital mammography, the geographic disparities we identified were temporary, as there are no film-based mammography providers remaining in New York State. Even at the peak of the disparity, in 2008, the public health impacts would not have been especially great as the diagnostic benefits of digital mammography were small. As such, other data sets might be better suited for highlighting the public health implications of differential access to medical technology, such as the diffusion of robotic surgery for treating prostate cancer (26). Our study did have the advantage of drawing upon a convenient population-based sample with a small number of well-specified procedure codes.

Maps and other forms of data visualization are useful for revealing patterns and local particularities likely to be overlooked in more conventional tabular presentations of results. Our approach here offers a straightforward and flexible means of visualizing the spatiotemporal distribution of competing medical procedures that could easily be expanded to accommodate any dichotomous variable. We follow in a long tradition of spatiotemporal mapping that has been used to depict the spread of ideas, technology, and disease (27, 28). The process has become much more technically straightforward in recent years, as our maps required only a single short R program rather than expertise in multiple commercial graphical software programs, as was the case for a previous cartographic animation of the spread of salmonella cases in the United States (29).

Smoothed maps require the sacrifice of detail in exchange for a more interpretable picture. One disadvantage of many smoothing methods is that areas with dense populations can have an undue influence on surrounding areas with sparse populations. In our analysis, this was actually the desired effect, as a place like Gloversville appeared to exert a wide influence because it was indeed the sole mammogram facility serving a large geographic area. In the case of disease rates or crime rates, there is less reason to think that a place like Gloversville would exert influence over outlying rural locations. Our maps may have embedded some border effects, however, as the data set was limited to New York State, and we had no way to capture any influence of towns in neighboring states. Our maps were also sensitive to our choice of smoothing parameter: we settled on a minimum of 50 mammograms per cell as striking the right balance between too noisy and too smoothed, but lowering or raising this value would have resulted in maps that were either more or less smoothed.

A final point is that the adoption of digital mammography did not result in any major change in the overall number of women receiving mammograms. According to survey data from the Center for Disease Control and Prevention’s Behavioral Risk Factor Surveillance System (30), the percentage of age-appropriate women receiving a mammogram within the past two years in New York State ranged between 80% to 85% between 2004 and 2012, with no clear trend.

Mammographic technology has not remained stable. Even as the final film-based machines were being taken out of service, the newer technology of tomosynthesis, or 3-dimensional mammography, was beginning to emerge. By taking images from many different angles, tomography captures far more information than a traditional 2-dimensional mammogram. A similar adoption and diffusion cycle has begun as with digital mammography. Tomography requires large initial investments from providers; it is not yet covered by many insurance plans, but Medicare began covering it in 2015. Studies suggest it is more accurate, resulting in both fewer false positives and fewer false negatives, but by small amounts (31). The amount of radiation exposure is slightly below that of 2-dimensional mammography. We might expect another "temporary" disparity to emerge from this technology - and to the extent that medical technology is continuously evolving, these temporary disparities are not in fact temporary at all.

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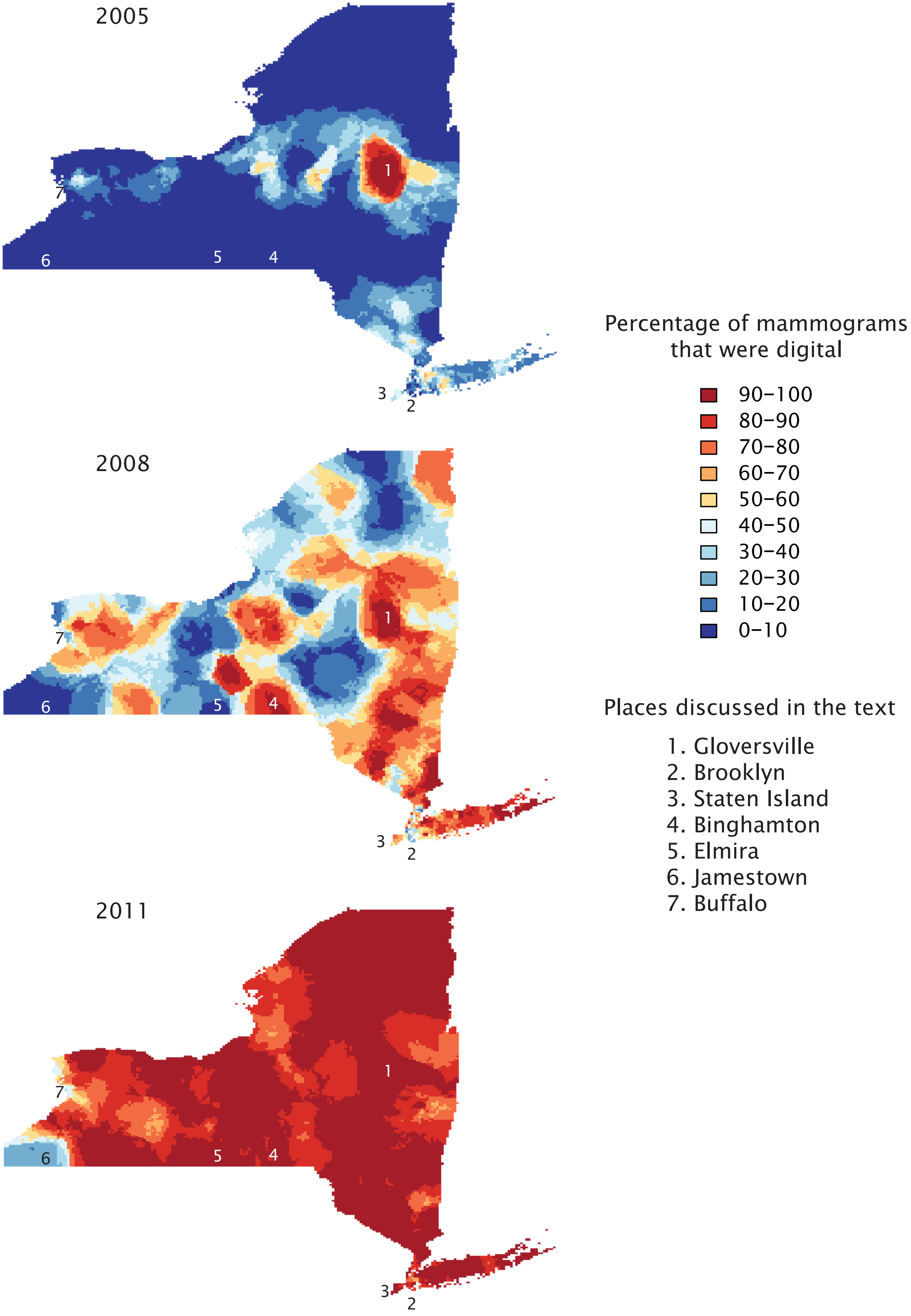

Figure 1. Percentage of mammograms that were digital, New York State, by zip code (smoothed), 2005, 2008, and 2011.

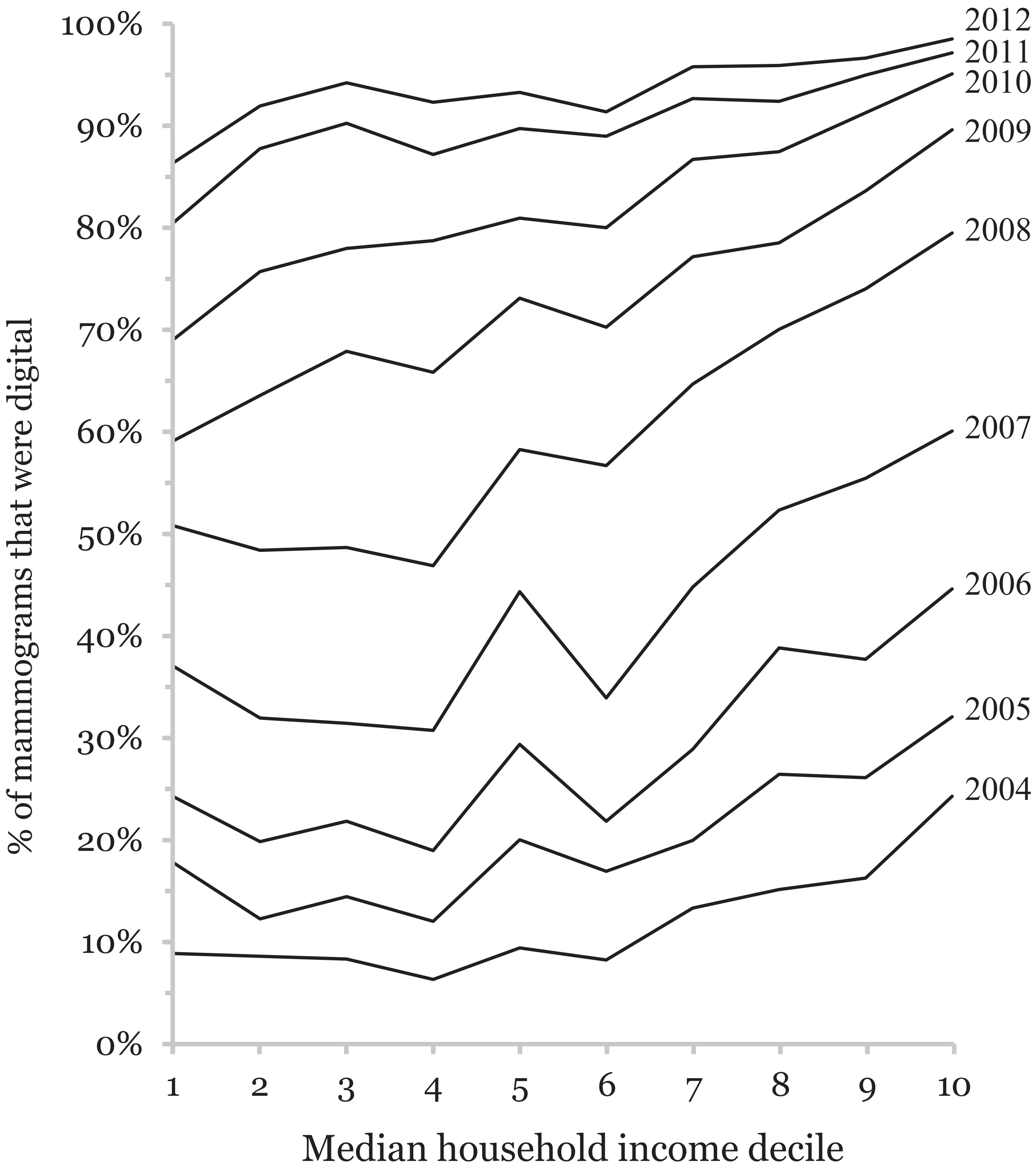

Figure 2. Relationship between digital screening mammography and median household income, 2004-2012.