Do CT Scans help prevent cancer-related deaths?

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Abstract

This paper uses a region-level estimation approach associated with medical procedures to identify the effectiveness of X-ray Computed Axial Tomography (CT) scans as a diagnostic tool in preventing cancer-related deaths. In order to measure the effects of the CT scan on cancer-related deaths, I use data from both the National Health Interview Survey and the Vital Statistics of the United States. For all four regions, we observe an increase in CT scan use after 1979 or, as illustrated specifically in the figure, from 1975 to 1980. All four regions exhibit marked increases in lung cancer-related deaths, very little fluctuation in the number of colon, liver, and stomach cancer-related deaths, and leukemia related deaths remain constant over the observed period; however, the base levels differ from region to region. The key identifying assumption for this study is that no other medical innovations or cancer-reducing policies that were established in a similar time period followed the same pattern as the expansion in use of the CT scan. In order to estimate the effect of the CT scan on select cancer-related death rates, I employ a linear OLS model, with the CT scan as the independent, right-hand side variable and the cancer-related death rate as the dependent, left-hand side variable. In addition, I control for observable characteristics, including a time trend, region fixed effects, and a control for region by year effects. I find statistically significant but suggestive evidence that increased CT scan use can lead to the decrease of lung cancer-related deaths. In addition, I find suggestive evidence that any increase in CT scan use will have no effect on leukemia related deaths. As described above, this finding is expected and confirms my methodology, as CT scans are not typically used to diagnose leukemia. On the other hand, my findings on the effect of CT scan use on colon, liver, and stomach cancer-related deaths is ambiguous. While imprecise, my estimates suggest that the CT scan is indeed an effective diagnostic tool in detecting some types of cancer, leading to a decrease in the number of deaths related to the given cancer.

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This paper uses a region-level estimation approach associated with medical procedures to identify the effectiveness of X-ray Computed Axial Tomography (CT) scans as a diagnostic tool in preventing cancer-related deaths. Correctly estimating these effects can have important implications for health policy and in improving cancer diagnostic techniques more generally. The analysis of the effectiveness of a medical procedure should take into account not only subsequent treatment following successful diagnosis, but all outcomes, including patient death. Estimates of the health effects of this scanning technology also have implications for health insurance policy and education and development of standard medical diagnostic procedures. Additionally, studying the effects of this standard diagnostic but potentially harmful procedure can provide insights into establishing a relationship between the costs and benefits of using this technology.

Though other processes for the detection of tumors were already available, the invention of the CT scan completely changed and enhanced physicians' abilities to not only isolate where along the vertical and horizontal axes a tumor or lesion has occurred, as was possible with projection radiography, but also determine the depth of the injury or growth. This allowed for early detection along with very important, and previously unattainable, new information. The additional information provided by finding the third coordinate of the disease should allow for more precise treatment, through surgery, targeted radiation therapy, or a combination of the two treatments and various others. Furthermore, enhanced precision in treatment should allow for more effective treatment; in the case of surgery, less invasive procedures may be used to remove a tumor, while in the case of radiation therapy, the entire body is spared high doses of potential harmful radiation as it is focused on the disease.

After initially conceptualizing it in the late 1960s, Sir Godfrey Hounsfield of the EMI Central Research Laboratories and Allan Cormack of Tufts University are credited as independently inventing the CT scanner in 1972. Following the instillation of the first commercial scanner in Atkinson Morley Hospital in Wimbledon, England, the first scanner in the United States was installed at the Mayo Clinic in Rochester, Minnesota. From this first installation, the CT scan grew swiftly in popularity and into medical diagnostic ubiquity. Despite this sustained diffusion, the rate of adoption of this technology varied across the four Census regions[1] of the U.S.

Almost since its creation in 1972, the CT scan has been included in medical and health educational literature[2] as a standard diagnostic procedure. Thus, due to its accepted medical utility, the CT scan has been largely neglected as focus for further study. Cutler and McClellan examined the benefits of medical innovation. While they found that the benefits of technological change in medicine outweighed the costs for heart attacks, low-birthweight infants, depression, and cataracts and the costs and benefits for breast cancer were equal, they concluded that medical spending as a whole is worth the increased cost of care. A few existing studies (notably Trajtenberg, 1989) have looked specifically

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[1] These regions are: Northeast, Midwest, South, and West.

[2] This includes *Squire's Fundamentals of Radiology*, which, since its initial publication in 1964, has become the textbook of choice for educating radiologists and other physicians.

at the CT scan in terms of its value as a product innovation, comparing the costs, benefits and the resulting total "profit" of the new product versus those of the older product. While the medical community has clearly come to the justified conclusion that the CT scan is indeed useful and effective in making positive diagnoses, the question of how effective the CT scan is has not been adequately investigated from an economic perspective.

However, due to possible risks associated with its use, the unconditional acceptance of the CT scan as a standard diagnostic procedure has faced considerable resistance from critics since its inception. In recent years, and especially in the past year, various medical studies have concluded that CT scan use has contributed to substantial increases in total cancer risk (Brenner and Hall, 2007; Berrington de Gonzalez, et al., 2008; Berrington de Gonzalez et al., 2009). These studies have looked at certain age groups and the relationship between their exposure and total cancer risk over time. While their conclusions yield estimates for future cancer rates, there is not substantial investigation into similar trends in the past and across various geographic regions in the United States.

In the West region, the use of CT scans grew the fastest out of the four regions, while usage grew slowest in the Northeast region. In addition, CT scan usage grew second fastest in the South region, while it grew at the next to last rate in the Midwest region. Thus, this current study utilizes a distinctive estimation strategy based on deviations in CT scans by region and year. Due to the nature of the diffusion of CT scan technology, some regions exhibited particularly high rates of CT scan use, while other regions showed either moderate or low rates of use. In addition, due to the relatively recent development of CT scan technology, compared to that of projection radiography, the years prior to the invention and acceptance of the CT scan show zero CT scan use, while in later years, CT scan usage rates fluctuate from year to year, showing periods of low, moderate, and high rates of CT scan use. Therefore, I use these year and region-level differences to measure both the positive and negative effects of CT scan usage on cancer-related deaths. Interview survey results of CT scan usage by year and region, as well as some selected cancer-related surgeries, are obtained from the National Health Interview Survey (NHIS). Specific cancer-related death rates, by year and region, are measured from the Vital Statistics of the United States (VSUS). In these specific cancer-related death rate data, I include data from a "test" cancer, one that should not be affected by any changes in CT scan usage. While medical literature suggests that the CT scan is often used to diagnose lung, colon, liver and stomach cancer, the CT scan is not a standard procedure used to diagnose leukemia.

The descriptive results from the data show an obvious trend break in the lung cancer-related deaths in certain regions, a very small trend break in colon, liver, and stomach cancer-related deaths in certain regions, and no trend break in leukemia related deaths. The estimates from this study are imprecise and vary across specifications; however, my preferred estimates indicate that faster diffusion of the CT scan is associated with declines in lung cancer deaths, small and possibly negative effects on colon, liver, and stomach cancer deaths, and no change in leukemia deaths. In addition, due to the ambiguity in the results measuring the effect of changes in CT scan use on cancer-related deaths from this study, I am unable to extrapolate and determine any secondary effect of changes in CT scan use, including the potential danger of an elevated risk of developing cancer from the relatively high dosage of radiation to which who receive CT scans are exposed.

II. Key Institutional Factors

CT scans could affect specific cancer-related deaths in two very distinct and opposite ways. Projection radiography, the precursor to CT scan technology and a viable diagnostic tool in its own right, was developed by Wilhelm Röntgen in 1895 and allowed for physicians and other medical professions to create a two-dimensional image, or projection, of a three-dimensional object. By subjecting the object to radiation at a specific energy level[3], the photographic film on the opposite side of the body is exposed by the incident radiation not absorbed by the body. CT scans use similar technology in that differential X-ray absorption is used to create images, however, rather than creating a single two-dimensional projection, multiple two-dimensional images, which are perpendicular to the same axis, are created and put together using various computational processes[4] to create a complete three-dimensional image of the object.

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[3] Due to the varying molecular structures of different parts of the body, X-rays, and other types of radiation, are absorbed unequally across the body. For example, since bones are denser than muscle tissue, bones absorb more X-ray radiation than muscle tissue. Thus, photographic film behind bones is underexposed, while film behind muscle tissue is usually overexposed, creating stark contrast and a subsequent decipherable image.

[4] These processes fall under the general category of computed tomography.

Although the CT scan does indeed provide an unprecedented and accurate view inside the body, the mechanism of the technology limits the types of cancer and other disease that can be observed and diagnosed using the scan. Since the production of the intermediate two – dimensional images is dependent on differential X-ray absorption, certain cancers will not present sufficient contrast to produce viable images. For instance, leukemia, a cancer of the bone marrow or blood characterized by an abnormal increase in blood cells (usually white cells), is not diagnosable by the CT scan since blood cells, in general, are not observable using differential X-ray absorption. In addition, since breast cancer tumors are generally closer to the surface of the skin, the enhanced vision provided by the CT scan over conventional projection X-ray scans is superfluous, and thus the CT scan is not typically used. On the other hand, lung cancer tumors often appear firmly rooted in the thoracic cavity. Conventional projection X-rays can indeed locate the tumor in a two-dimensional plane, but CT scans provide a precise three-dimensional perspective of where exactly the tumor lies relative to other essential organs and fragile tissue. In Figure 1, Panel A illustrates the results of a projection radiograph. In this radiograph, the varying depths of organs and other tissue cannot be determined since the method of projected causes a loss of information about this third dimension. Panel B, on the other hand, shows one two-dimensional "slice" of the patient, which, when aggregated with the other "slices" gives information about the spatial orientation of the observed organs and tissue. Therefore, lung cancer is often diagnosed using the CT scan. Colon, liver and stomach cancers are abdominal analogs to lung cancer and, as such, are diagnosed and often treated in a similar fashion.

III. Data

i. Data Sources

As mentioned above, in order to measure the effects of the CT scan on cancer-related deaths, I use data from both the National Health Interview Survey (NHIS) and the Vital Statistics of the United States (VSUS). The NHIS is a detailed survey, published by the National Center for Health Statistics (NCHS), a division of the Center for Disease Control and Prevention (CDC), which serves as the principal source of information about the health and related issues of the civilian population of the United States. Covering a very large spectrum of variables, the NHIS provides a continuing survey and special studies to secure accurate and current statistical information on the amount, distribution, and effects of illness and disability in the United States and the services rendered for or because of such conditions. For the purposes of this analysis, I used the Hospital Record[5] to establish how many CT scans were performed in the sample in a given year and region and the sample weights of the given year in order to estimate the number of CT scans performed in that year. By dividing the number of CT scans performed in each region the sample by the sample weight of the given year, I created my own variable representing the percentage of the population that received CT scans in a given year and region. Due to fluctuating

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[5] The NHIS data is arranged into 5 different sections (the Household Record, Person Record, Condition Record, Doctor Visit Record, and the Hospital Record) in order to establish more manageable data sets for the user. For this analysis, the Hospital Record was used as it specifically takes into account hospital-based procedures and hospitalizations.

interview policy and procedural changes, as well as evolving budgetary constraints of the CDC and NHIS, the number of observations varied greatly. As a result, the estimate for the number of CT scans performed across the population in a given year was rather noisy on a year-to-year basis. Therefore, I elect to condense the data on CT scans to 5-year groups. Not only does this condensation allow for more readily interpretable data, but also removes the dulling effect of noise on any estimated effects between CT scan use and cancer-related deaths. In addition, due to irreconcilable changes in the definitions of variables, I restricted the span under study to a thirty-year period, from 1963 to 1993. Data for the CT scan is not available from the NHIS until it was included as a variable in 1979. Thus, CT scan use data is reported as zero before 1979.

The VSUS, on the other hand, is another comprehensive report published by the NCHS with a very different set of available data. Though there is a wide array of information available, the VSUS includes very in-depth information in only four main areas – mortality, natality, marriage, and divorce. For this study, I used mortality data to identify how many specific cancer – related deaths occurred in a given year and region. The variables were reported as "Number of Deaths per 100,000"[6] and were used as reported. As described above, rather than evaluating all cancer – related deaths, I choose to evaluate three specific cancers and the deaths associated with them. In particular, I looked at leukemia, lung, colon, liver, and stomach cancer-related deaths. Although five different types of cancer are

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[6] Though this variable definition and unit of measurement may seem awkward in relation to the units of CT scan use, which is reported as a percentage, the difference is reconciled with a short series of dimensional analysis in the Results section of this paper to establish a tangible and easily understood value.

accounted for, due to the way in which the variables are defined in the VSUS, colon, liver, and stomach cancers are represented by the same variable. Figure 2 illustrates two-dimensional "slices" from relevant cancers and a micrograph of leukemia. Panel A shows a two-dimensional "slice" from the CT scan of a patient with lung cancer whose tumor is indicated by the red arrows, while Panel B shows a two-dimensional "slice" from the CT scan of a patient with liver cancer whose tumor is indicated by the black arrows. Panel C, on the other hand, shows the stained micrograph of the blood of a patient with leukemia. As mentioned in the key institutional factors, the nature of leukemia inhibits its detection by CT scan. In order to accurately compare the cancer-related death data to the CT scan data, I elected, for similar reasons, to also condense the cancer-related death data for 5-year groups over the same thirty-year period as used with the CT scan data.

ii. Descriptive Results

Figure 3 illustrates the change in CT scan use from 1963 to 1993. For all four regions, we observe an increase in CT scan use after 1979 or, as illustrated specifically in the figure, from 1975 to 1980. However, the magnitudes of the increase in CT scan use varied widely from region to region. In the West region, the increase is most pronounced, going from zero to a usage rate of 4.7% in just 10 years. The CT scan usage rate grows next fastest in the South region, increasing from zero to 4.5% in 15 years. Next, the CT scan usage rate peaks at 3.2% in 10 years in the Midwest region. Finally, in the Northeast region, the CT scan usage rate peaks at 1.9% after 15 years, showing by far the slowest and smallest growth in CT scan usage across all four regions.

Figure 4 shows the change in lung cancer-related deaths from 1963 to 1993. All four regions exhibit marked increases in lung cancer-related deaths over the period, however, the base levels differ from region to region; the Northeast and South have similar levels of lung cancer-related deaths, while the Midwest region has a lower level and the West region has a significantly lower level than the other three. There is no clear break in the upward trend in mortality for the Midwest and South regions, there appears to be a trend break in both the West and Northeast regions approximately around the time that CT scan use began to increase in both regions.

Figure 5 illustrates the change in colon, liver, and stomach (CLS) cancer-related deaths from 1963 to 1993. In this case, all four regions exhibit very little fluctuation in the number of CLS cancer-related deaths over the observed period. However, once again, the base levels of the death rates differ from region to region. It is interesting to note that the base level is once again the highest in the Northeast region, the lowest by far in the West region, and the Midwest and South regions round out the middle. Unlike the lung cancer-related death rates, there is a slight but ambiguous indication of any trend break in any of the regions. For instance, CLS cancer-related death rates appear to level off after 1975, while the other regions have highly oscillatory and noisy trends.

Finally, Figure 6 shows the change in leukemia related deaths from 1963 to 1993. As with CLS cancer death rates, leukemia related deaths seem to remain constant over the period of observation. As is the case with lung cancer-related deaths and CLS cancer-related deaths, the lowest death rate related to leukemia can be found in the West region. However, unlike in the previous accounts, the

Northeast region exhibits only the second highest base level of leukemia related deaths, with the Midwest region coming in with the highest level and the South region with the second lowest level of leukemia related deaths. As expected by an assumption of this study, there appears to be no trend break of leukemia related deaths in any region, since CT scans would not be used in the diagnosis of leukemia.

IV. Results

i. Model

The key identifying assumption for this study is that no other medical innovations or cancer-reducing policies that were established in a similar time period followed the same pattern as the expansion in use of the CT scan. Furthermore, I attempt to account for this assumption through looking at the "test" cancer (leukemia) regression in which I hypothesize the coefficient to be zero. In order to estimate the effect of the CT scan on select cancer-related death rates, I employ a linear OLS model, with the CT scan as the independent, right-hand side variable and the cancer-related death rate as the dependent, left-hand side variable. In addition, I control for observable characteristics, including a time

$$(1) \qquad Deaths_{r,t} = \alpha_r * CTScan_{r,t} + \delta_{r,t}$$

trend, region fixed effects, and a control for region by year effects.

Though these controls account for a reasonable amount of omitted variable bias, since the CT scan rate is measured from a sample, the estimates will be biased toward zero, and additional controls could exacerbate the bias (Griliches 1977, 1979). Although the CT scan allows for earlier detection and therefore there may be a lag between CT scan use and a change in cancer-related mortality, this study does not look into what that lag may be, but rather that there is any relationship between CT scan use and cancer-related deaths.

Ideally, in order to most accurately estimate the effect of the CT scan on cancer-related deaths, the estimation strategy would be composed of a two-stage regression. Rather than estimating the effect of the CT scan directly on cancer-related deaths, adding a second equation measuring the successful detection and diagnosis of a cancer using the CT scan would yield a much more precise result. The first equation would estimate the effect of changes in CT scan use on cancer-related treatment, while the second equation would then estimate the effect of changes in cancer-related treatment on cancer-related deaths. Initially, I attempted to use evidence from cancer-related surgeries as a proxy for measuring the affirmative detection and diagnosis of a cancer as well as an indication of a cancer-related treatment. Although surgery data is readily available from the NHIS, the variable definitions change substantially from 1978 to 1979, leading to either sharp drop offs or spikes in the cancer-related surgery rate. The resulting data set could therefore not be used to accurately measure any relationship between changes in CT scan use and cancer-related surgeries. However, if a more reliable source for cancer-related surgery is created or produced, using this two-stage model could possibly yield a more convincing result.

ii. Empirical Results

Table 1 presents estimates of the effects of CT scan use on cancer-related deaths using data from the NHIS and the VSUS samples as described above.

Panel A shows estimates for lung cancer – related deaths, panel B shows estimates for CLS cancer-related deaths, and panel C shows estimates for leukemia related deaths. Within each panel, each subsequent column shows a different regression using a different set of controls. The regressor of interest is "CT Scans / Population". Columns (1) through (4) include OLS estimates using all four regions, while columns (5) through (8) show OLS estimates using just the Northeast and West regions. The motivation for removing the Midwest and South regions and attempting to measure the effect in the other two reasons arises from the stark and obvious contrast in the growth of CT scan use in the selected regions. Columns (1) and (5) do not include controls, while columns (2) and (6) control for a time trend, columns (3) and (7) control for both a time trend and region fixed effects, and columns (4) and (8) control for a time trend, region fixed effects, and region by year effects.

Without any controls, as is the case in columns (1) and (5), the estimates are not significant, most likely due to substantial omitted variable bias. Similarly, while columns (4) and (8) have all three controls included, the estimates carry little significance since the low number of observations leads to very few remaining degrees of freedom and high measurement error bias, diminishing the viability of the estimates drastically. On the other hand, the estimates from columns (2) and (6) must be interpreted cautiously. As described in the discussion of the data, there are tangible differences in the nature of both cancer-related deaths and the growth of CT scan use between regions, and although the region fixed effects are not included, the estimates in column (6) are significant across all the panels. Finally, I choose the estimates in column (7) to be the preferred estimates of the study from which further conclusions will be drawn due to the significance of at least the estimate of the effect of CT scan use on lung cancer-related deaths and an adequate number of controls that appropriately strikes a balance between omitted variable bias and measurement error bias.

The estimated coefficients in Table 1 represent the change in the number of specific cancer-related deaths per 100,000 in the total population due to an increase in CT scan usage such that 100% of the population receives a CT scan. Using the preferred estimation as indicated above, the interpretation of the coefficients is as follows. The estimate for panel A in column (7) suggests that there is a negative relationship between CT scan use and lung cancer-related deaths such that as CT scan usage is increased, the number of deaths related to lung cancer decreases. For panel B, the estimate yields insignificant coefficients, and thus this study accurately indicate whether or not changes in CT scan use results in a change in CLS cancer-related deaths. Finally, the estimate for panel C suggests that there is no relationship between increased CT scan use and deaths related to leukemia. Though this may at first seem like a troubling result, it is indeed expected, because, as described above, the CT scan is not designed to detect and diagnosis leukemia. Therefore, this neutral result controls for the any plausible natural decrease in cancer-related deaths in general.

The main reason for the variability across specifications is the small sample size. However, the measurement error bias is driven by a slightly different problem in that CT scans are measured from a sample and do not appear to be an accurate measure of prevalence from year-to-year. Therefore, estimating the effect from a relatively small sample exacerbates this measurement error, leading to imprecise estimates of the time trend and region fixed effects. The units of the estimate coefficient represent a rather far-fetched scenario where the rate of CT scan use jumps from 1.3%, which is the mean of the acquired CT scan use data, to 101.3%. Thus, rather than measuring the estimation as a decrease in lung cancer-related deaths by -115.1, CLS cancer related deaths by -31.32, and -5.326 per 100,000 in the total population due to a 100% increase in CT scan use, I choose to modify the estimates using a simple formula to instead measure the change in cancer-related deaths due to an increase in CT scan use equivalent to doubling the sample mean of CT scan use.

These results can be found in Table 2. As before, since columns (1) and (5) have no controls, the estimates are not significant. On the other hand, columns (4) and (8) include all the controls, and due to the low number of observations, the estimates suffer from a high level of measurement error bias and very few remaining degrees of freedom. In addition, the results from columns (2) and (6) are not very reliable because they do not include controls for region fixed effects. Once again, I choose the results from column (7) to be my preferred results. We say that, when the CT scan rate is doubled from a mean of 1.3% to 2.6%, this leads to a decrease in lung cancer-related deaths by 3.5%. The results for both CLS cancer-related deaths and leukemia related deaths show a change of less than a percent, and are not significant.

It is useful to examine the total costs of undertaking the development and dissemination of a medical technology like the CT scan per life saved. In order to do so, it is necessary to calculate the costs of inventing and spreading the CT scan and how much higher cancer-related deaths would have been had the CT scan never been invented. However, data on the costs of developing the CT scan are not widely available and therefore could not be estimated. Still, given the estimates from Table 2, lung cancer-related deaths would have been approximately 45 deaths per 100,000 higher had the CT scan not being put into use.

V. Conclusion

This study exploits differences across different regions from 1963 to 1993 to estimate the effects of the CT scan, as a cancer screening technology, on colon, liver, stomach, leukemia, and lung cancer related deaths. I find statistically significant but suggestive evidence that increased CT scan use can lead to the decrease of lung cancer-related deaths. In addition, I find suggestive evidence that any increase in CT scan use will have no effect on leukemia related deaths. As described above, this finding is expected and confirms my methodology, as CT scans are not typically used to diagnose leukemia. On the other hand, my findings on the effect of CT scan use on colon, liver, and stomach cancer-related deaths is ambiguous. While imprecise, my estimates suggest that the CT scan is indeed an effective diagnostic tool in detecting some types of cancer, leading to a decrease in the number of deaths related to the given cancer.

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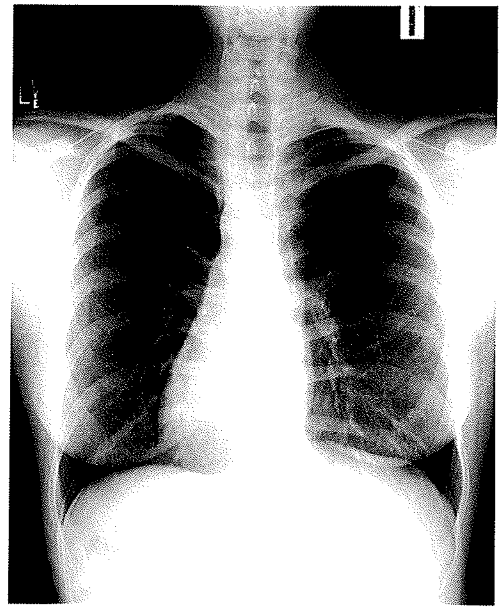
Figure 1: Examples of Radiographic Information Available to Physicians

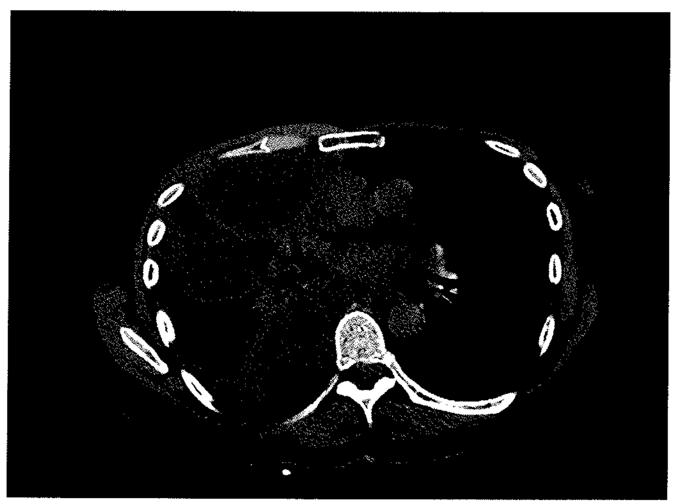
Panel A: Projection X - Ray Scan of the Chest



[7]

Panel B: Two - dimensional "slice" used in a CT scan

[8]

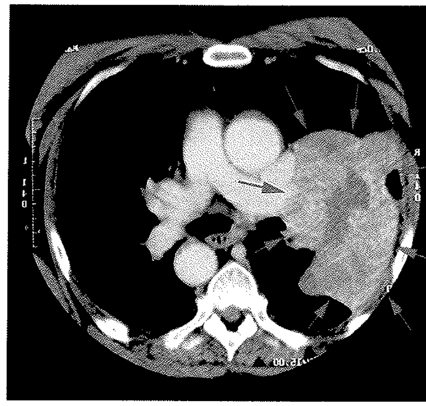


[7] http://www.aztechradiology.com/Services/XRay/tabid/128/Default.aspx

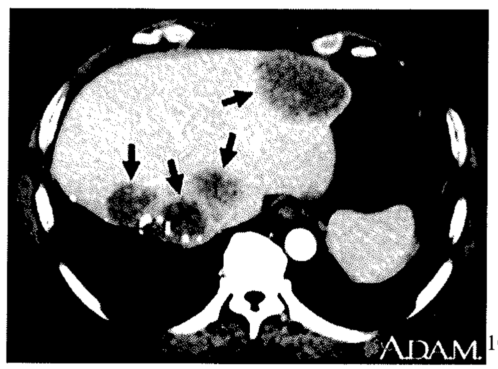
[8] http://www.biomedcentral.com/1471-2334/6/18/figure/F1?highres=y

Figure 2: Two-Dimensional "Slices" from Relevant Cancers and Micrograph of Leukemia

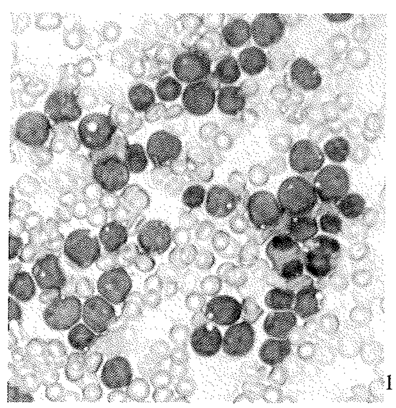
Panel A: Two dimensional "slice" from CT Scan of patient with Lung Cancer


[9]

Panel B: Two dimensional "slice" from CT Scan of patient with Liver Cancer


[10]

Panel C: Stained Micrograph of Leukemia Patient; Not observable using CT Scan


[11]

[9] http://www.tobacco-facts.info/images_html/lung_cancer_ct-scan-3.htm

[10] http://www.nlm.nih.gov/medlineplus/ency/imagepages/1180.htm

[11] http://www.stanford.edu/group/cleary/leukemia.jpg

Figure 3: CT Scan Rate in 5-year groups from 1963-1996

Figure 4: Lung Cancer Death Rate in 5-Year groups from 1963-1993

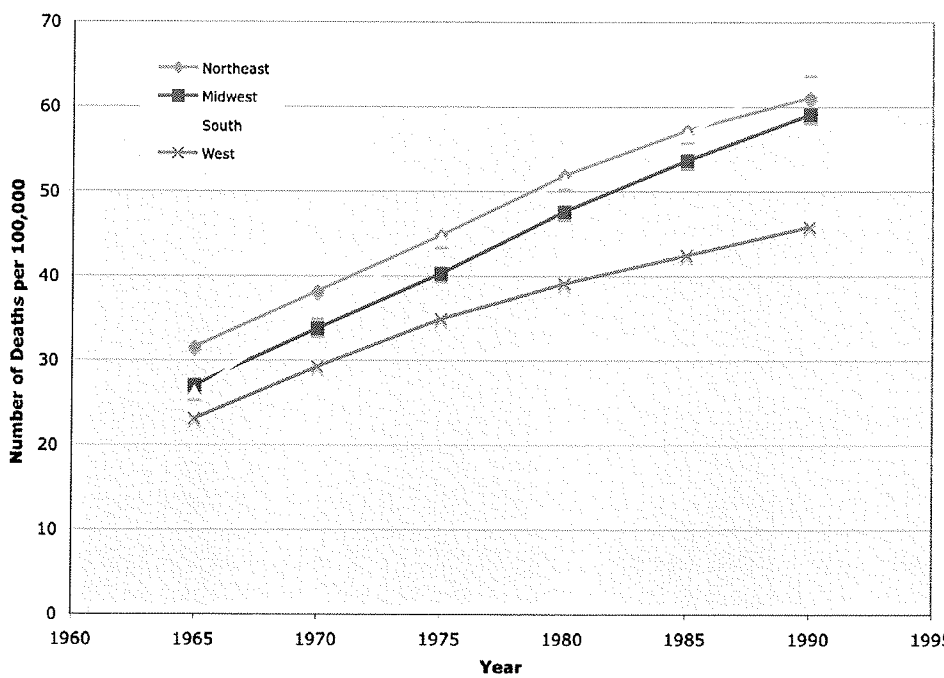


Figure 5: Colon, Liver, and Stomach Cancer Death Rate in 5-Year groups from 1963-1993

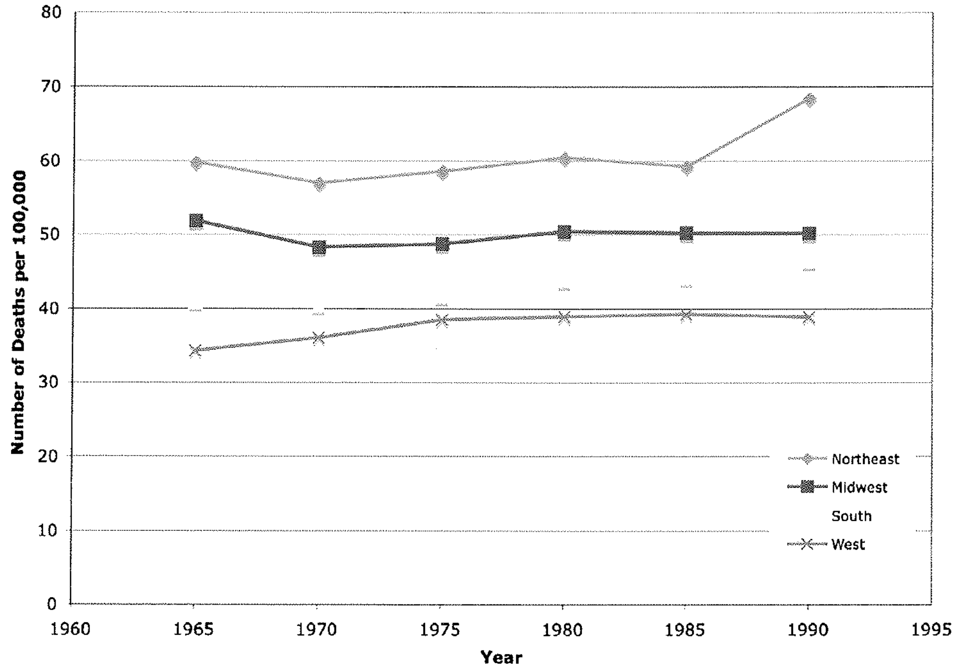


Figure 6: Leukemia Death Rate in 5-Year groups from 1963-1993

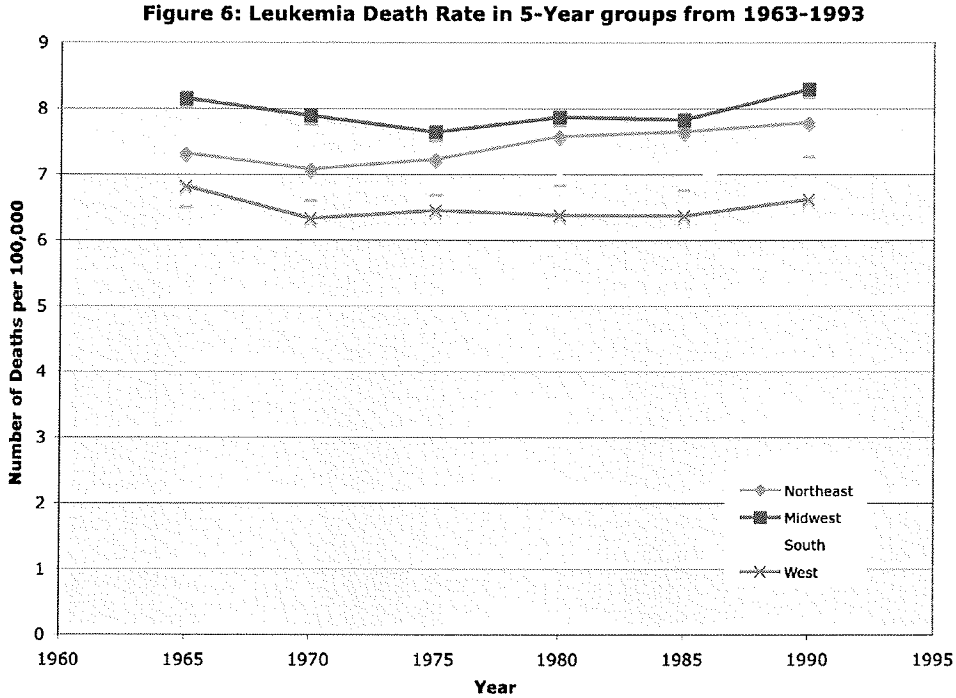


Table 1: OLS Regression of Region-Level Cancer Deaths on Region-Level CT Scan Rates, 1963-1993

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		All Regions				Only West and Northeast		
	Panel A: Dependent Variable is Lung Cancer Deaths per 100,000 Persons, (Mean = 43.34)							
CT Scans / Pop (Mean = 0.01301)	531.4 (145.3)***	-193.3 (136.3)	-42.08 (56.60)	-45.63 (32.93)	335.1 (193.7)	-394.8 (131.3)**	-115.1 (43.99)**	-39.47 (45.71)
R^2	0.4747	0.8301	0.9695	0.9943	0.2064	0.7942	0.9838	0.9922
	Panel B: Dependent Variable is Colon, Liver, and Stomach Cancer Deaths per 100,000 Persons, (Mean = 47.77)							
CT Scans / Pop (Mean = 0.01301)	-27.40 (100.5)	-394.9 (191.3)*	25.77 (53.34)	44.74 (37.79)	-121.8 (191.3)	-621.2 (264.1)**	-31.32 (66.20)	-1.030 (52.97)
R^2	0.0021	0.1576	0.9581	0.9703	0.0231	0.2563	0.9704	0.9715
	Panel C: Dependent Variable is Leukemia Deaths per 100,000 Persons, (Mean = 7.196)							
CT Scans / Pop (Mean = 0.01301)	1.589 (8.680)	-15.12 (14.03)	1.211 (6.576)	5.129 (6.323)	-6.286 (8.394)	-28.82 (10.91)**	-5.326 (4.675)	4.315 (8.149)
R^2	0.0016	0.0746	0.8905	0.9310	0.0318	0.2770	0.8623	0.9221
Time Trend		Yes	Yes	Yes		Yes	Yes	Yes
Region FEs			Yes	Yes			Yes	Yes
Region X Year				Yes				Yes
N (Region x 5-year interval)	24	24	24	24	12	12	12	12

*Notes to Table 1: Within each panel, each column shows results from a separate ordinary least squares regression. The level of observation is the broad U.S. Census region by 5-year interval. Outcome data are missing for 1965; consequently, the first period includes the six-year interval from 1963 to 1968. Robust standard errors appear in parentheses beneath each coefficient estimate. ***, **, and * indicate 1%, 5%, and 10% significance, respectively*

Table 2: Computed Percent Change in Number of Deaths per 100,000 Resulting from a Doubling of the CT Scan Use Rate (from the mean value of 0.01301 up to 0.02602)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		All Regions				Only West and Northeast		
	Panel A: Dependent Variable is Lung Cancer Deaths per 100,000 Persons							
Δ% in Number of Deaths per 100,000	0.1594 (0.04360)***	-0.05802 (0.04090)	-0.01263 (0.01698)	-0.01369 (0.009883)	0.1005 (0.05813)	-0.1185 (0.03941)**	-0.03453 (0.01320)**	-0.01184 (0.01371)
	Panel B: Dependent Variable is Colon, Liver, and Stomach Cancer Deaths per 100,000 Persons							
Δ% in Number of Deaths per 100,000	-0.007462 (0.02735)	-0.1075 (0.05208)*	0.007017 (0.01452)	0.01218 (0.01029)	-0.03316 (0.05208)	-0.1691 (0.07192)**	-0.008530 (0.01802)	-0.0002806 (0.01442)
	Panel C: Dependent Variable is Leukemia Deaths per 100,000 Persons							
Δ% in Number of Deaths per 100,000	0.00287 (0.01569)	-0.02733 (0.02537)	0.002188 (0.01188)	0.009272 (0.01143)	-0.01136 (0.01517)	-0.05211 (0.01971)**	-0.009629 (0.008452)	0.007801 (0.01473)
Time Trend		Yes	Yes	Yes		Yes	Yes	Yes
Region FEs			Yes	Yes			Yes	Yes
Region X Year				Yes				Yes
N (Region x 5-year interval)	24	24	24	24	12	12	12	12

*Notes to Table 2: Within each panel, each column shows results from computing the percent change in the number of deaths per 100,000. Robust standard errors appear in parentheses beneath each coefficient estimate. ***, **, and * indicate 1%, 5%, and 10% significance, respectively. Standard errors were computed using the delta method.*

Written Summary (for a non-expert audience)

This paper attempts to identify the effectiveness of X-ray Computed Axial Tomography (CT) scans as a diagnostic tool in preventing cancer-related deaths. Correctly estimating these effects can have important implications for health policy and in generally improving cancer diagnostic techniques. Estimates of the health effects of this scanning technology also have implications for health insurance policy, healthcare education and development of standard medical diagnostic procedures. Additionally, studying the effects of this standard, but potentially harmful, diagnostic procedure can provide insights into establishing a relationship between the costs and benefits of using this technology.

CT scans could affect specific cancer-related deaths in two very distinct and opposite ways. Projection radiography, the precursor to CT scan technology and a viable diagnostic tool in its own right, was developed by Wilhelm Röntgen in 1895 and allowed for physicians and other medical professions to create a two-dimensional image, or projection, of a three-dimensional object. By subjecting the object to radiation at a specific energy level, the photographic film on the opposite side of the body is exposed by the incident radiation not absorbed by the body. CT scans use similar technology, in that differential X-ray absorption is used to create images. However, rather than creating a single two-dimensional projection, multiple two-dimensional images, which are perpendicular to the same axis, are created and put together using various computational processes to create a complete three-dimensional image of the object.

Though other processes for the detection of tumors were already available, the invention of the CT scan completely changed and enhanced physicians' abilities to not only isolate where along the vertical and horizontal axes a tumor or lesion has occurred, as was possible with projection radiography, but also determine the depth of the injury or growth. This allowed for early detection along with very important, and previously unattainable, new information. The additional information provided by finding the third coordinate of the disease should allow for more precise treatment, through surgery, targeted radiation therapy, or a combination of the two treatments along with various others. Furthermore, enhanced precision in treatment should allow for more effective treatment; in the case of surgery, less invasive procedures may be used to remove a tumor, while in the case of radiation therapy, the entire body is spared high doses of potentially harmful radiation as it is focused on the disease.

Although the CT scan does indeed provide an unprecedented and accurate view inside the body, the mechanism of the technology limits the types of cancer and other disease that can be observed and diagnosed using the scan. Since the production of the intermediate two – dimensional images is dependent on differential X-ray absorption, certain cancers will not present sufficient contrast to produce viable images. For instance, leukemia, a cancer of the bone marrow or blood characterized by an abnormal increase in blood cells (usually white blood cells), is not diagnosable by the CT scan since blood cells, in general, are not observable using differential X-ray absorption. In addition, since breast cancer tumors are generally closer to the surface of the skin, the enhanced vision provided by the CT scan over conventional projection X-ray scans is superfluous, and thus the CT scan is not typically used. On the other hand, lung cancer tumors often appear firmly rooted in the thoracic cavity. Conventional projection X-rays can indeed locate the tumor in a two-dimensional plane, but CT scans provide a precise three-dimensional perspective of where exactly the tumor lies relative to other essential organs and fragile tissues.

After initially conceptualizing it in the late 1960s, Sir Godfrey Hounsfield of the EMI Central Research Laboratories and Allan Cormack of Tufts University are credited as independently inventing the CT scanner in 1972. Following the instillation of the first commercial scanner in Atkinson Morley Hospital in Wimbledon, England, the first scanner in the United States was installed at the Mayo Clinic in Rochester, Minnesota. From this first installation, the CT scan grew swiftly in popularity and into medical diagnostic ubiquity. Despite this sustained diffusion, the rate of adoption of this technology varied across the four Census regions (Northeast, Midwest, South, and West) of the U.S.

Almost since its creation in 1972, the CT scan has been included in medical and health educational literature as a standard diagnostic procedure. Thus, due to its accepted medical utility, the CT scan has been largely neglected as focus for further study. A few existing studies have looked specifically at the CT scan in terms of its value as a product innovation, comparing the costs, benefits and the resulting total "profit" of the new product versus those of older products. While the medical community has clearly come to the justified conclusion that the CT scan is indeed useful and effective in making positive diagnoses, the question of how effective the CT scan is has not been adequately investigated from an economic perspective.

However, due to possible risks associated with its use, the unconditional acceptance of the CT scan as a standard diagnostic procedure has faced considerable resistance from critics since its inception. In recent years, and especially in the past year, various medical studies have concluded that CT scan use has contributed to substantial increases in total cancer risk. These studies have looked at certain age groups and the relationship between their exposure and total cancer risk over time. While their conclusions yield estimates for future cancer rates, there is not substantial investigation into similar trends in the past and across various geographic regions in the United States.

In the West region, the use of CT scans grew the fastest out of the four regions, while usage grew slowest in the Northeast region. CT scan usage grew second fastest in the South region, while it grew at the next to last rate in the Midwest region. Thus, this current study utilizes a distinctive estimation strategy based on deviations in CT scans by region and year. Due to the nature of the diffusion of CT scan technology, some regions exhibited particularly high rates of CT scan use, while other regions showed either moderate or low rates of use. In addition, due to the relatively recent development of CT scan technology, compared to that of projection radiography, the years prior to the invention and acceptance of the CT scan show zero CT scan use, while in later years, CT scan usage rates fluctuate from year to year, showing periods of low, moderate, and high rates of CT scan use. Therefore, I use these year and regional differences to measure both the positive and negative effects of CT scan usage on cancer-related deaths. Interview survey results of CT scan usage by year and region, as well as some selected cancer-related surgeries, are obtained from the National Health

Interview Survey (NHIS). Specific cancer-related death rates, by year and region, are measured from the Vital Statistics of the United States (VSUS). In these specific cancer-related death rate data, I include data from a "test" cancer, one that should not be affected by any changes in CT scan usage. While medical literature suggests that the CT scan is often used to diagnose lung, colon, liver and stomach cancer, the CT scan is not a standard procedure used to diagnose leukemia.

The descriptive results from the data show an obvious trend break in the lung cancer-related deaths in certain regions, a very small trend break in colon, liver, and stomach cancer-related deaths in certain regions, and no trend break in leukemia related deaths. The estimates from this study are imprecise and vary across specifications. However, my preferred estimates indicate that faster diffusion of the CT scan is associated with declines in lung cancer deaths, small and possibly negative effects on colon, liver, and stomach cancer deaths, and no change in leukemia deaths. In addition, due to the ambiguity in the results measuring the effect of changes in CT scan use on cancer-related deaths from this study, I am unable to extrapolate and determine any secondary effect of changes in CT scan use, including the potential danger of an elevated risk of developing cancer from the relatively high dosage of radiation to which those whom receive CT scans are exposed to.