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Lightning, IT Diffusion and Economic Growth across US States*

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Abstract: Empirically, a higher frequency of lightning strikes is associated with slower growth in labor productivity across the 48 contiguous US states after 1990; before 1990 there is no correlation between growth and lightning. Other climate variables (e.g., temperature, rainfall and tornadoes) do not conform to this pattern. A viable explanation is that lightning influences IT diffusion. By causing voltage spikes and dips, a higher frequency of ground strikes leads to damaged digital equipment and thus higher IT user costs. Accordingly, the flash density (strikes per square km per year) should adversely affect the speed of IT diffusion. We find that lightning indeed seems to have slowed IT diffusion, conditional on standard controls. Hence, an increasing macroeconomic sensitivity to lightning may be due to the increasing importance of digital technologies for the growth process.

Keywords: Climate; IT diffusion; economic growth
JEL Classification: O33, O51, Q54

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1. Introduction

We are by all accounts living in a time of global climate change. This is a good reason to explore the economic consequences of climate related characteristics. In particular, how does the climate influence the growth process?

There seems to be compelling evidence to suggest that climate and geography profoundly affected the historical growth record (Diamond, 1997; Olsson and Hibbs, 2005; Putterman, 2008; Asraf and Galor, 2008). Today, climate shocks, like temperature changes, still affect growth in poor countries (Dell et al., 2008). But are climate and geography also important in highly developed economies, where high-tech industry and services are dominant activities?

Some research suggests that geography is still a force to be reckoned with, even in rich places. Access to waterways, for instance, appears to matter (Rappaport and Sachs, 2003). However, a geographic characteristic that exhibits a *time-invariant* impact on prosperity is difficult to disentangle from other slow moving growth determinants that may have evolved under the influence of climate or geography. In particular, climate and geography probably influenced the evolution of economic and political institutions.[1]

The present paper documents that a particular climate related characteristic – lightning activity – exhibits a *time-varying* impact on growth in the world's leading economy. Studying the growth process across the 48 contiguous US states from 1977 to 2007, we find no impact from lightning on growth prior to about 1990. However, during the post 1990 period there is a strong negative association: states where lightning occurs at higher frequencies have grown relatively more slowly. What can account for an increasing macroeconomic sensitivity to lightning?

In addressing this question one may begin by noting that the 1990s was a period of comparatively rapid US growth; it is the period where the productivity slowdown appears to

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[1] An apparent impact from diseases on comparative development may be convoluting the impact from early property rights institutions in former colonies (Acemoglu et al., 2001); the impact of access to waterways, as detected in cross-country data, may also be related to the formation of institutions (Acemoglu et al., 2005).

finally have come to an end. Furthermore, the 1990s is the period during which IT appears to have diffused throughout the US economy at a particularly rapid pace. In fact, IT investment is often seen as a key explanation for the US growth revival (e.g., Jorgenson, 2001). On a state-by-state basis, however, the process of IT diffusion (measured by per capita computers and Internet users as well as manufacturing firms' IT investments) did not proceed at a uniform speed.

An important factor that impinges on IT investment and diffusion is the quality of the power supply. That a high quality power supply is paramount for the digital economy is by now widely recognized. As observed in *The Economist*:[2]

> *For the average computer or network, the only thing worse than the electricity going out completely is power going out for a second. Every year, millions of dollars are lost to seemingly insignificant power faults that cause assembly lines to freeze, computers to crash and networks to collapse.* […] *For more than a century, the reliability of the electricity grid has rested at 99.9%* […] *But microprocessor-based controls and computer networks demand at least 99.9999% reliability* […] *amounting to only seconds of allowable outages a year.*

Indeed, a sufficiently large power spike lasting only one millisecond is enough to damage solid state electronics such as microprocessors in computers. Therefore, as a simple matter of physics, an irregularly fluctuating power supply reduces the longevity of IT equipment, and thus increases the user cost of IT capital.

A natural phenomenon that causes irregular voltage fluctuations is lightning activity. Albeit the impulse is of short duration, its size is impressive. Even in the presence of lightning arresters on the power line, peak voltage emanating from a lightning strike can go as high as 5600 V, which far exceeds the threshold for power disruptions beyond which connected IT equipment starts being damaged (e.g., Emanuel and McNeil, 1997). Moreover, the influence from lightning is quantitatively important. To this day, lightning activity causes around one third of the total number of annual power disruptions in the US (Chisholm and Cummings,

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[2] "The power industry's quest for the high nines", *The Economist*, March 22, 2001.

2006). Theoretically, it is therefore very plausible that lightning may importantly have increased IT user costs.[3] Consequently, in places with higher IT user cost one would expect a slower speed of IT diffusion; lightning prone regions may be facing a climate related obstacle to rapid IT diffusion. It is worth observing that the problems associated with lightning activity, in the context of IT equipment, has not gone unnoticed by the private sector. As *The Wall Street Journal* reports:[4]

> *Even if electricity lines are shielded, lightning can cause power surges through unprotected phone, cable and Internet lines - or even through a building's walls. Such surges often show up as glitches. "Little things start not working; we see a lot of that down here," says Andrew Cohen, president of Vertical IT Solutions, a Tampa information-technology consulting firm. During the summer, Vertical gets as many as 10 calls a week from clients with what look to Mr. Cohen like lightning-related problems. Computer memory cards get corrupted, servers shut down or firewalls cut out.*

Even though a link between lightning and IT diffusion is plausible, it does not follow that the link is economically important in the aggregate. Nor is it obvious that IT can account for the lightning-growth correlation.

We therefore also study the empirical link between lightning and the spread of IT across the US. IT is measured from both the household side (Internet and computer use) and the firm side (manufacturing firms' IT investment rates). We find that the diffusion of IT has progressed at a considerably slower pace in areas characterized by a high frequency of lightning strikes. This link is robust to the inclusion of a large set of additional controls for computer diffusion. Moreover, lightning ceases to be correlated with growth post 1990, once controls for IT are introduced. While the lightning-IT-growth hypothesis thus seems well founded, other explanations cannot be ruled out *a priori*.

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[3] Naturally, the "power problem" may be (partly) addressed, but only at a cost. The acquisition of surge protectors, battery back-up emergency power supply (so-called uninterruptable power supply, UIP) and the adoption of a wireless Internet connection will also increase IT user costs through the price of investment. Hence, whether the equipment is left unprotected or not, more lightning prone areas should face higher IT user cost.

[4] "There Go the Servers: Lightning's New Perils". *Wall Street Journal*, August 25, 2009.

An alternative explanation is that the correlation between growth and lightning picks up growth effects from global warming. If global warming has caused lightning to increase over time, and simultaneously worked to reduce productivity growth, this could account for the (reduced form) correlation between lightning and growth. We document that this is unlikely to be the explanation for two reasons. First, we show that from 1906 onwards US aggregate lightning is stationary; on a state-by-state basis, we find the same for all save two states. There is thus little evidence to suggest that lightning density is influenced by a global warming induced trend. Second, we attempt to deal with the potential omitted variables problem by controlling directly for climate shocks which also could be induced by climate change. We examine an extensive list of climate variables, including rainfall, temperature and frequency of tornadoes. None of these variables impacts on the correlation between lightning and state-level growth rates. Nor does any other climate variable exhibit the kind of time-varying impact on growth that we uncover for lightning.

Another potential explanation is that the lightning-growth correlation is picking up "deep determinants" of prosperity that exhibit systematic variation across climate zones, just as lightning does. For instance, settler mortality rates, the extent of slavery and so forth. However, the correlation between lightning and growth is left unaffected by their inclusion in the growth regression.

In sum, we believe the most likely explanation for the lightning-growth correlation is to be found in the diffusion mechanism. The analysis therefore provides an example of how technological change makes economies increasingly sensitive to certain climate related circumstances. This finding is consistent with the "temperate drift hypothesis" (Acemoglu et al., 2002), which holds that certain climate related variables may influence growth in some states of technology, and not (or in the opposite direction) in others.

The paper is related to the literature that studies technology diffusion; particularly diffusion of computers and the Internet (e.g., Caselli and Coleman, 2001; Beaudry et al., 2006; Chinn and Fairlie, 2007). In line with previous studies, we confirm the importance of human capital for the speed of IT diffusion. However, the key novel finding is that climate related circumstances matter as well: lightning influences IT diffusion. In this sense the paper complements the thesis of Diamond (1997), who argues for an impact of climate on technology diffusion. Yet, whereas Diamond argues that climate is important in the context of agricultural technologies, the present paper makes plausible that climate also matters to technology diffusion in high-tech societies.

The analysis proceeds as follows. In the next section we document the lightning-growth link. Then, in Section 3, we discuss likely explanations (IT diffusion, other forms of climatic influence, institutions and integration) for the fact that lightning correlates with growth from about 1990 onwards. Section 4 concludes.

2. Lightning and US growth 1977-2007

This section falls in two subsections. In Section 2.1 we present the data on lightning and discuss its time series properties. In particular, we demonstrate that lightning is stationary and that, for panel data purposes, it is best thought of as a state fixed effect. Next, in Section 2.2, we study the partial correlation between lightning and growth across the US states.

2.1 The Lightning Data

The measure of lightning activity that we employ is the *flash density*, which captures the number of ground flashes per square km per year. We have obtained information about the flash density from two sources. The first source of information is reports from weather stations around the US. From this source we have yearly observations covering the period 1906-1995 and 40 US states. From about 1950 onwards we have data for 42 states. The second source of information derives from ground censors around the US. This data is *a priori* much more reliable than the data from weather stations.[5] In addition, it is available for all 48 contiguous states, but it only comes as an average for the period 1996-2005.[6]

In order to understand the data better, we begin by studying its time series properties. Figure 1 shows the time path for *aggregate* US lightning over the period 1906-95.

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[5] Lightning events recorded at weather stations are based on audibility of thunder (i.e., these are basically recordings of thunder days), whereas ground sensors measure the electromagnetic pulse that emanates from lightning strikes (i.e., these are recordings of actual ground strikes). In the context of IT diffusion it is ground strikes that matter, and not the type of lightning occurring between clouds, say.

[6] Further details are given in the Data Appendix.

>Figure 1 about here<

The aggregate flash density is calculated as the state size weighted average over the 40 states with data for this extended period. Visual inspection suggests that there is no time trend. To test whether lightning contains a stochastic trend, we use an augmented Dickey-Fuller (DF) test with no deterministic trend. Lag length is selected by minimizing the Schwarz information criterion with a maximum of five lags. For aggregate US lightning the optimal lag length is one and the DF statistic equals -4.516. Hence the presence of a unit root is resoundingly rejected.

At the state level the presence of a unit root is also rejected at the 5% level in 38 of the 40 states, cf. Table 1. In light of the fact that DF tests have low power to reject the null of a unit root (even more so when, as here, we do not include a deterministic trend), we are in all likelihood safe to conclude that state-level lightning is also stationary.

>Table 1 about here<

These findings are of some independent interest in that they suggest that global warming has not interfered with the evolution of lightning trajectories in the US in recent times. In other words, there is little basis for believing that the flash density has exhibited a trend during the last century.

In the analysis below we focus on the period from 1977 onwards, dictated by the availability of data on gross state product. Consequently, it is worth examining the time series properties of the lightning variable during these last few decades of the 20th century.

During this period the flash density is for all practical purposes a fixed effect. In the Appendix, Table A.1, we show state-by-state that the residuals obtained from regressing lightning on a constant are serially uncorrelated. That is, deviations of the flash density from time averages are, from a statistical perspective, white noise. To show this formally, we use the Breusch-Godfrey test and a Runs test for serial correlation. By the standards of the Breusch-Godfrey test, we cannot reject the null hypothesis of no serial correlation in 38 states out of 42 states;

using the Runs test, we fail to reject the null in 40 states. Importantly, no state obtains a p-value below 0.05 in both tests. This suggests that for the 1977-95 period lightning is best described as a state fixed effect.

As remarked above, we have an alternative source of data available to us, which contains information for the 1996-2005 period. How much of a concurrence is there between data for the 1977-95 period and the data covering the end of the 1990s and early years of the 21st century? Figure 2 provides an answer. Eyeballing the figure reveals that the two measures are very similar. In fact, we cannot reject the null that the slope of the line is equal to one. This further corroborates that lightning is a state fixed effect.

>Figure 2 about here<

These findings have induced us to rely on the data deriving from ground censors in the analysis below. As noted above, this latter lightning data is of a higher quality compared to the measure based on weather stations and it covers more US states. Moreover, since deviations from the average flash density are white noise, we lose no substantive information by resorting to a time invariant measure. Still, it should be stressed that using instead the historical lightning measure based on weather stations (or combining the data) produces the same (qualitative) results as those reported below. These results are available upon request.

The cross-state distribution of the 1996-2005 data is shown in Figure 3, whereas summary statistics for 1996-2005 are provided in Table 2.

>Figure 3 about here<
>Table 2 about here<

There is considerable variation in the flash density across states. At the lower end we find states like Washington, Oregon and California with less than one strike per square km per year. It is interesting to note that the two states which are world famous for IT, Washington and California, are among the least lightning prone. At the other end of the spectrum we find Florida, Louisiana and Mississippi with seven strikes or more. It is clear that lightning varies systematically across climate zones. Hence, it is important to check, as we do below, (i) that lightning's correlation with growth is not due to other climate variables like high winds, rainfall and so on; and (ii) that spatial clustering effects are not deflating standard errors.

2.2 The Emergence of a Lightning-Growth Nexus

Figures 4 and 5 show the partial correlation between growth in labor productivity and the flash density, controlling only for initial labor productivity.

>Figures 4 and 5 about here<

We have data on gross state product (GSP) per worker for the period 1977-2007.[7] Hence, for this first exercise we have simply partitioned the data into two equal sized 15 year epochs. As seen from the two figures, there is a marked difference in the partial correlation depending on which sub-period we consider. During the 1977-92 period there is no association between growth and lightning; the (OLS) point estimate is essentially nil. However, in the second sub-period the coefficient for lightning rises twenty fold (in absolute value) and turns statistically significant; places with higher flash density have tended to grow at a slower rate during the 1990s and the first decade of the 21st century.

While this exercise is revealing, there is no particular reason to believe that the lightning-growth correlation emerged precisely in 1992. Hence, to examine the issue in more detail, we study the same partial correlation by running "rolling" regressions over 10 year epochs, starting with 1977-87.[8] That is, letting G_{it} denote the percentage average annual (continuously compounded) growth rate of GSP per worker over the relevant 10 year epoch,[9] we estimate an equation of the following kind:

$$G_{it} = b_0 + b_1 \log(y_{it-10}) + b_2 \log(\text{lightning}_i) + \varepsilon_i,$$

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[7] State level data on personal income is also available, and for a longer period. But personal income does not directly speak to productivity. By contrast, GSP per worker is a direct measure of state level labor productivity. Moreover, the GSP per worker series is available in constant chained dollar values, which is an important advantage in the context of dynamic analysis. See the Data Appendix for a description of the GSP per worker series.

[8] The exact choice of time horizon does not matter much; below we run regressions with 5, 10, and 15 year epochs that complement the present exercise.

[9] That is, $G_{it} = 100*(1/T)*\log(y_{it}/y_{it-T})$, where T = 10.

and examine the evolution of b_2 as t increases. Figure 6 shows the time path for b_2 as well as the associated 95% confidence interval.

>Figure 6 about here<

In the beginning of the period there is not much of a link between lightning and growth; if anything the partial correlation is positive. As one moves closer to the 1990s the partial correlation starts to turn negative and grows in size (in absolute value). By 1995 the lightning-growth correlation is statistically significant at the 5% level of confidence. As one moves forward in time the partial correlation remains stable and significant. Hence, this exercise points to the same conclusion as that suggested by Figures 4 and 5: the negative partial correlation between lightning and growth emerged in the 1990s.

Albeit illustrative, both exercises conducted so far are *ad hoc* in the sense that they do not allow for a formal test of whether the impact from lightning is rising over time. Hence, as a final check, we run panel regressions with period length of 5, 10, and 15 years. The results are reported in Table 3 below.

>Table 3 about here <

Since lightning, for all practical purposes, is a fixed effect (cf. Section 2.1), Table 3 reports the results from running pooled OLS regressions. Specifically, we estimate the following growth regression:

$$G_{it} = b_0 + b_1 \log(y_{it-T}) + b_{2t} \log(\text{lightning}_i) + \mu_t + \varepsilon_{it},$$

where T=5, 10, 15 and b_{2t} accordingly is allowed to vary from period-to-period by way of interaction with time dummies. This way we can track the statistical and economic significance of lightning over time. Note also that we include time dummies independently of lightning, so as to capture a possible secular trend in growth over the period in question.

Turning to the results we find that the impact of lightning increases over time, and turns statistically significant during the 1990s.[10] The significance of lightning is particularly noteworthy as it is obtained for the relatively homogenous sample of US states. As is well known, the growth process for this sample is usually fairly well described by the initial level of income alone, suggesting only modest variation in structural characteristics that impinge upon long-run labor productivity (e.g., Barro and Sala-i-Martin, 1992). As a result, the scope for omitted variable bias contaminating the OLS estimate for lightning is *a priori* much more limited than, say, in a cross-country setting.

Still, a potential concern is that the lightning-growth correlation could be due to the omission of human capital. As is well known the return on skills appears to have risen during the 1990s, which could suggest an increasing effect from education on growth. If, in addition, the level of education is negatively correlated with lightning intensity (and it is) the lightning-growth link might disappear once schooling is introduced.

In Table 4 we therefore add measures of human capital to the growth regression. In order to do so rigorously we add information on primary, secondary and tertiary education simultaneously. As the lightning correlation does not depend appreciably on whether we invoke 5, 10 or 15 year epoch length we have chosen to focus on 10 year epochs. Results for 5 and 15 year epochs are similar, and available upon request.

>Table 4 about here <

Columns 2-5 of the table reveal that the human capital measures have no bearing on the lightning-growth correlation relative to the baseline growth regression in column 1; lightning is always significant irrespective of whether the three human capital proxies are added one-by-one (cf. columns 2-4) or included jointly (cf. column 5).

Another concern relates to regional effects. As is visually clear from Figure 3, lightning density is characterized by a certain degree of geographical clustering. Such cluster effects may

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[10] The general time dummies (not reported) corroborate the prior of a revitalization of productivity growth during the 1990s.

impinge on the analysis in several ways.[11] Most importantly, one may worry that the lightning-growth correlation simply reflects that the Southeast, a high lightning area, is growing more slowly for reasons unrelated to lightning during this period. This suggests that we should add regional fixed effects to the growth regression.

In this endeavor we rely on the economic areas classification used by the Bureau of Economic Analysis (BEA), which distinguishes between eight regions.[12] This classification is however very taxing for our results in the sense that regressing the eight BEA areas on (log) lightning explains 84% of the cross state lightning variation (cf. Appendix, Table A.2, column 4).

In columns 6 of Table 4 we add the eight regional fixed effects. The inclusion of the BEA regions does not impinge on the *size* of the partial correlation between lightning and growth, but it impacts on the *precision* of the OLS estimate in a major way, by doubling the standard error. This is no surprise in light of the strong degree of multicollinearity between the regional effects and lightning intensity. This interpretation is further supported by the fact that while neither lightning nor the set of fixed effects are significant separately, they are jointly significant. In order to examine whether regional effects are at the root of the lightning-growth correlation, we therefore also ran regressions where we add each of the regional fixed effects one-by-one to the specification in column 5 of Table 4. The results are found in the Appendix (Table A.3). The key result is that no single BEA region can render lightning imprecise enough to be rejected as statistically insignificant.

In sum, the time varying effect of lightning on growth is not produced by the growth performance of any particular region, is robust to the inclusion of human capital and time dummies. The specification in column 5 of Table 4 will serve as our baseline specification when we examine the robustness of the lightning-growth link in much greater detail.

Before addressing robustness in depth, however, it is worth commenting on the economic significance of lightning. Taken at face value, the point estimate for the 1990s imply that a one

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[11] See Cameron and Trivedi (2005) or Angrist and Pischke (2009) for general discussions of clustering.

[12] The eight BEA regions are Far West, Great Lakes, Mideast, New England, Plains, Rocky Mountain, Southeast, and Southwest.

standard deviation increase in lightning intensity (about 2.4 flashes per year per sq km) induces a reduction in growth by about 0.2 percentage points $(\approx 0.2 \cdot \log(2.4))$, conditional on the level of initial labor productivity, human capital and the time effects. This is about 12.5 % of the gap between the 5th percentile and the 95th percentile in the distribution of GSP per worker growth rates for the period 1977-2007 (for the 48 states in our sample). By extension, variation in lightning by four standard deviations (roughly equivalent to moving from the 5th percentile to the 95th percentile in the lightning distribution across US states) can account for about 50% of the "95/5" growth gap.[13] Needless to say, this is a substantial effect.

3. Robustness of the Lightning-growth nexus

3. 1 Climate Shocks

At first glance, a reasonable objection to the lightning-growth correlation is that it is somehow spurious: perhaps other climate related variables exert an impact on growth and, at the same time, happen to be correlated with the flash density?

To be sure, lightning correlates with various kinds of weather phenomena that arise in the context of thunderstorms. Aside from lightning, thunderstorms produce four weather phenomena: tornadoes, high winds, heavy rainfall, and hailstorms. It seems plausible that these climate variables can induce changes in the growth rate in individual states in their own right. Each of them destroy property (physical capital), people (human capital), or both (Kunkel et al., 1999). By directly affecting the capital-labor ratio, the consequence of, say, a tornado could be changes in growth attributable to transitional dynamics. The nature of the transitional dynamics (i.e., whether growth rises or falls) is unclear as it may depend on whether the tornado destroys more physical or human capital (e.g., Barro and Sala-i-Martin, 1995, Ch.5).[14] Nevertheless, since the lightning-growth correlation pertains to a relatively short time span (so far), it is hard to rule out that the above reasoning could account for it.

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[13] Log normality of lightning is not accurate; but on the other hand not terribly misleading either. It does exaggerate the actual variation in lightning slightly; the observed variation is about 7 flashes, compared to the "back-of-the-envelope" calculation implying roughly 9.

[14] In a US context one may suspect a relatively larger impact on physical capital compared to human capital; if so climate shocks would tend to instigate a growth acceleration in their aftermath, as a higher marginal product of capital induces firms to invest in physical capital.

In addition, lightning correlates with temperature: hotter environments usually feature a higher flash density. Temperature has been documented to correlate with economic activity within countries (e.g., Nordhaus, 2006; Dell et al., 2009); therefore, we cannot rule out *a priori* that the link between lightning and growth is attributable to the intervening influence of temperature.[15]

Hence, in an effort to examine whether climate shocks could account for the lightning-growth correlation, we gathered data on all of the above weather phenomena: temperature, precipitation, tornadoes, hail size and wind speed. In addition, we obtained data on topography (i.e., elevation) and latitude. The latter is a useful catch-all measure of climate. For good measure, we also obtained data on sunshine, humidity, and cloud cover (albeit it is not entirely clear why these weather phenomena should matter to growth). In total, we have data on ten alternative climate/geography variables; the details on the data are found in the Data Appendix.

With these data in hand, we ask two questions. First, ignoring lightning, do any of these weather phenomena exhibit a correlation with growth which is similar to that of lightning? That is, do any of them appear to become more strongly correlated with growth during the period 1977-2007? Second, taking lightning into account, do any of the above mentioned variables render lightning insignificant?

Tables 5 and 6 report the answers. Columns 2-11 of Table 5 examine the potentially time varying impact from each weather variable; column 1 reproduces the lightning regularity from Section 2.1. It is plain to see that none of the weather variables exhibit a similar growth correlation as that involving lightning. The only variable that influences growth in a statistically significant way in the final period is hail size; however, unlike lightning, hail size also had a statistically significant growth impact in the first period.

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[15] Nordhaus (2006) and Dell et al. (2009) document a correlation between temperature and income *levels,* not growth*.* In fact, Dell et al. (2008) find that temperature is *not* correlated with growth in rich places, using cross-country data. Nevertheless, the link seems worth exploring.

>Tables 5 and 6 about here<

In Columns 2-11 of Table 6 we simultaneously include lightning and the various alternative climate/geography controls. In all cases, lightning remains significantly correlated with growth. In fact, when comparing the point estimate for lightning with or without (column 1) additional controls, it emerges that the point estimate is virtually unaffected.

In sum, these results suggest that the lightning-growth correlation is unlikely to be attributable to other weather phenomena.

3.2 Institutions and Integration

An extensive literature examines the impact from historical factors on long-run development. For instance, variation in colonial strategies seems to have an important impact on institutional developments around the world, thus affecting comparative economic development (e.g., Acemoglu et al., 2001). Similarly, initial relative factor endowments, determined in large part by climate and soil quality, may well have affected long-run development through inequality and human capital promoting institutions (Engerman and Sokoloff, 2002; Galor et al., 2008). Thus, in many instances the initial conditions that may have affected long-run developments are related to climate or geography. In the present context, therefore, it seems possible that the lightning-growth correlation may be picking up the influence from such long-run historical determinants of prosperity. Naturally, the conventional understanding would be that "deep determinants of productivity", e.g. determinants of political and economic institutions, should have a fairly time invariant impact on growth. As a result, it would not be surprising if such determinants do not exert a time varying impact on growth. But whether it is the case or not is obviously an empirical matter.

To examine whether the lightning-growth nexus is attributable to such effects, we obtained data on ten potential determinants of long-run performance for the US. The source of the data is Mitchener and McLean (2003), who examine the determinants of long-run productivity levels across US states. In addition, we collected state-level data on three dimensions of global integration, related to international movements of goods and capital. This leaves us with 13 different potential determinants of labor productivity growth, broadly capturing "institutions, geography and integration" (Rodrik et al., 2004).[16]

As in Section 3.1 we ask whether these determinants, individually, exhibit a time varying impact on growth, and whether their inclusion in the growth regression renders lightning insignificant.

>Table 7 and 8 about here<

In Table 7 we examine the impact from various historical determinants of productivity one-by-one. Of particular note is column 4, which involves the percentage of the population in slavery in 1860. This is the only variable which behaves much like lightning, with a partial correlation that seems stronger at the end of the 1977-2007 period as compared to the beginning of the period.

Table 8 includes both lightning and the individual controls. Since the population in slavery is the only variable we have found so far that exhibits a correlation with growth that is qualitatively similar to that of lightning, the results reported in column 4 is of central importance. When both variables enter the growth regression only lightning retains explanatory power. The point estimate for the last period is more or less unaffected, while the statistical significance of lightning is reduced a bit. But population in slavery does not statistically dominate lightning in the specification. More broadly, it is once again worth observing how stable the partial correlation between lightning and growth seems to be. Comparing the results reported in column 1 (no historical controls) for lightning to those reported in columns 2-11 it is clear that the coefficient for lightning is quite robust.

Finally, Table 9 examines the potential influence from integration. As seen by inspection of columns 4 and 5, integration proxies cannot account for the lightning-growth correlation either.

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[16] See the Data Appendix for details.

>Table 9 about here<

The results of this and the previous subsection uniformly support the same qualitative conclusion: a macro economic sensitivity to lightning has emerged over time in the US. The question is why?

4. An explanation for the Lightning-Growth nexus: IT diffusion

We begin this section by examining the theoretical foundation behind the claim that lightning (or, more appropriately, the flash density) should have an impact on growth via IT diffusion. Subsequently we examine the hypothesis empirically.

4.1. Theory: why lightning matters to IT diffusion.

The simplest way to think about IT diffusion is via basic neoclassical investment theory. That is, IT diffusion occurs in the context of IT capital investments; higher investments are tantamount to faster IT diffusion.

According to neoclassical investment theory, the central determinant of the desired capital stock, and thus investments for the initial stock given, is the user cost of capital (Hall and Jorgenson, 1967). Two elements of (IT) user cost are plausibly influenced by lightning: the total price of IT investment goods and the physical rate of IT capital depreciation.

IT capital depreciation is influenced by lightning activity for the following physical reason. Solid-state electronics, such as computer chips, are constructed to deal with commercial power supply in the form of alternating current. The voltage of the current follows a sine wave with a specific frequency and amplitude. If the sine wave changes frequency or amplitude, this constitutes a power disruption. Digital devices convert alternating current to direct current with a much reduced voltage; digital processing of information basically works by having transistors turn this voltage on and off at several gigahertz (Kressel, 2007). If the power supply is disrupted, the conversion process may become corrupted, which in turn causes damage to the equipment, effectively reducing its longevity. It is important to appreciate that even extremely short lasting power disruptions are potentially problematic.

Voltage disturbances measuring less than one cycle (i.e., 1/60th of a second in the US case) are sufficient to crash and/or destroy servers, computers, and other microprocessor-based devices (Yeager and Stalhkopf, 2000; Electricity Power Research Institute, 2003). A natural phenomenon which damages digital equipment, by producing power disruptions, is lightning activity (e.g., Emanuel and McNeil, 1997; Shim et al., 2000, Ch. 2; Chisholm, 2000).[17] This avenue of influence is *a priori* highly plausible. In the US lightning produces a large fraction of the total number of power disruptions (Chisholm and Cummings, 2006); firms specializing in delivering power protection are another testimony to the same thing.

The latter point immediately raises the issue that firms can take pre-emptive actions so as to reduce the impact of lightning on the cost of capital. This can be done by investing in surge protectors, say. However, the crux of the matter is that this imposes an additional cost to be carried in the context of IT investments; it amounts to an increasing IT investment price. Hence, even if we take the likely pre-emptive measures into account, more lightning prone areas will face higher IT user costs.

In sum: in areas with a greater flash density, the speed of IT diffusion, as measured by IT capital accumulation, will proceed at a slower pace. The reason is that a higher lightning density increases the frequency of power disturbances, IT capital depreciation (or the price of IT investments), the user cost of IT capital, and thus lowers IT investments. Moreover, if output is increasing in the IT capital stock, growth in output will similarly tend to be slower in areas with greater lightning activity, conditional on the initial level of output.

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[17] Note that lightning may enter a firm or household in four principal ways. First, lightning can strike the network of power, phone, and cable television wiring. This network, particularly when elevated, acts as an effective collector of lightning surges. The wiring conducts the surges directly into the residence, and then to the connected equipment. In fact, the initial lightning impulse is so strong that equipment connected to cables up to 2 km away from the site of the strike can be damaged (BSI, 2004). Technically speaking, this is the mechanism we are capturing in the simple model above. Second, when lightning strikes directly to or nearby air conditioners, satellite dishes, exterior lights, etc., the wiring of these devices can carry surges into the residence. Third, lightning may strike nearby objects such as trees, flagpoles, road signs, etc., which are not directly connected to the residence. When this happens, the lightning strike radiates a strong electromagnetic field, which can be picked up by the wiring in the building, producing large voltages that can damage equipment. Finally, lightning can strike directly into the structure of the building. This latter type of strike is extremely rare, even in areas with a high lightning density.

While the above theoretical considerations speak to a direct impact of lightning on IT investment, there could be an important complementary mechanism at work. The *choice of firm location* may depend on the quality of power supply, and thus lightning. Specifically, it may be the case that IT intensive firms choose to locate in areas where lightning intensity is modest, due to the resulting (slightly) higher power quality. Interestingly, the National Energy Technology Laboratory, operated by the US Department of Energy, reports that a recent firm level survey had 34% respondents saying that they would shift business operations out of their state if they experienced ten or more unanticipated power disturbances over a quarter of a year.[18] Hence, it seems plausible that this mechanism also could affect comparative IT penetration across US States.

To this one may add that in areas with frequent power disruptions and outages, the marginal *benefit* of owning a computer is probably lowered as well. Obviously, if consumers and firms face regular power outages it will be difficult to employ IT efficiently. But even if power disruptions are infrequent and of very short duration, power disruptions lead to glitches and downtime, which serves to lower the productivity of IT equipment. Hence, aside from increasing the marginal costs of IT capital, lightning may also work to lower IT productivity.

Schematically we may summarize the theoretical considerations above in the following way:

Lightning density → Power disturbances→ IT investments→Growth,

where the second from last arrow subsumes the likely impact from (lightning induced) power disturbances on IT costs and benefits.

The mechanisms linking lightning to growth are likely to have become increasingly important over time for a number of reasons. First, IT capital investments accounted for a substantial part of output growth, starting in the 1990s (e.g., Jorgenson, 2001). Consequently, factors that impact on IT capital accumulation (e.g., the flash density) should also become more important to growth. Second, the 1990s was the era during which the Internet emerged (in the sense of

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[18] The report is available at: http://www.netl.doe.gov/moderngrid/

the World Wide Web); a conceivable reason why firms chose to intensify IT investments during the same period.[19] From a physical perspective, however, the network connection is another way in which lightning strikes may reach the computer, in the absence of wireless networks (which have not been widespread until very recently). Third, the 1990s saw rapid increases in the computing power of IT equipment. In keeping with Moore's law, processing speed doubled roughly every other year. This is an important propagation mechanism of the lightning-IT investment link. The reason is that the sensitivity of computers to small power distortions *increases* with the miniaturization of transistors, which is the key to increasing speed in microprocessors (Kressel, 2007).[20] As a result, these factors would all contribute to increasing the importance of the flash density to IT investments, and thus to growth, during the 1990s. Whether this theory is relevant, however, is an empirical issue to which we now turn.

4.2. Empirical analysis: Lightning, IT diffusion and Economic Growth.

In order for the above theory to be able to account for the lightning-growth correlation, two things need be true. First, it must be the case that lightning is a strong predictor of IT across the US states. Second, there should be no explanatory power left in lightning vis-à-vis growth once we control for IT. We examine these two requirements in turn.

In measuring the diffusion of IT capital across the US we employ three different measures. Two measures derive from a supplement to the 2003 Current Population Survey, which contained questions about computer and Internet use; the third measure derives from the 2007 Economic Census (see Data Appendix for further detail). The first measure is percentage of households with access to the Internet; the second measure is percentage of households with a PC; and the third measure is manufacturing firms' capital expenditures on computers

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[19] The WWW was launched in 1991 by CERN (the European Organisation for Nuclear Research). See Hobbes' Internet Timeline v8.2 http://www.zakon.org/robert/internet/timeline/ .

[20] This is well known in the business world: "*The spread of technology has spawned a need for lightning-security specialists." The computer chip, the smaller it's gotten, the more susceptible it is," says Mark Harger, owner of Harger Lightning and Grounding in Grayslake, Ill. "It's been a boon to our business". His company manufacturers systems that shield buildings from direct strikes and power surges from nearby lightning. With a steady stream of orders from financial and technology companies looking to protect their data centers, the company has gone from eight employees to 100 over the past 20 years.* ""There Go the Servers: Lightning's New Perils", *The Wall Street Journal*, August 25, 2009.

and related equipment as a percentage of total capital expenditures on machinery and equipment.[21] A few comments on the IT data are in order.

First, our IT measures allow us to explore IT penetration in the US economy from two different perspectives: the firm and the household side, respectively. Whereas the household data speaks exclusively to the level of IT investments, the firm data arguably speaks both to IT investments and location choice. In the end there are two reasons why the fraction of IT expenditures to total capital expenditure might be higher in some states compared to others. On the one hand there is the *investment effect*, which captures that structurally similar manufacturing firms have different levels of IT investments, depending on whether they locate in high versus low lightning density areas; this sort of information is also likely captured by our household data. However, on the other hand, there is a potential *composition effect*, which captures that areas with less lightning may attract more IT intensive firms, which drives up the IT expenditure/Total capital expenditure ratio. Both effects, which we admittedly cannot disentangle, would predict a negative relationship between lightning density and manufacturing IT investment intensity.

Second, one may worry about vintage capital effects. In a vintage growth setting a higher (lightning induced) rate of capital depreciation will in principle have two opposite effects on the IT capital stock. One the one hand, we expect lower overall investments. On the other hand, faster depreciation implies that more recent (more productive) vintages take up a larger share of the stock. As a result, one may worry about the net impact of lightning on IT capital and long-run productivity. Unfortunately we do not have access to information about IT quality, which would be ideal. Still, on *a priori* grounds, a higher rate of capital depreciation unambiguously lowers IT capital *intensity* in the standard neoclassical vintage growth model (Phelps, 1962). Hence, even allowing for vintage effects, higher depreciation should lower IT

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[21] We did consider inferring IT capital intensity at the state level since the Bureau of Economic Analysis produces sector specific data on IT capital stocks. To exploit these data we would have to assume that the marginal product of IT capital is equalized *within* sectors, *across* states. Weighting the sector specific IT capital intensities by state specific sector composition would yield a guesstimate for state IT capital intensity. However, since (state specific) lightning affects the user cost of capital via the price of acquisition and/or the rate of capital depreciation, the assumption of within industry equalization of marginal products is implausible on *a priori* grounds. To put it differently, the main avenue through which lightning should affect IT capital intensity would be eliminated *by construction* had we used this procedure to generate state level IT capital. As a result, we have not pursued the matter further.

intensity and thereby long-run productivity. Moreover, if the IT variable is measured with gross error, it would tend to make it less likely that it appears as a significant growth determinant in the regressions to follow at the end of this section; i.e., it would make it less likely that IT (as measured here) can account for the lightning-growth correlation.[22]

Third, with only one observation for the IT variables, we have to settle for cross section regressions.

Finally, one may question whether there is value in using both household IT variables, since having access to a computer is a prerequisite for the use of the Internet. Yet, the emergence of the WWW is a much more recent technology than the PC, as the former derives from 1991. The personal computer started spreading earlier. Hence, the initial conditions that may matter to the speed of adoption are discernible by time. For instance, whereas educational attainment in the 1970s should influence the spread of the personal computer, the Internet is affected by education levels in the 1990s. Consequently, the two empirical models of IT diffusion will have to differ in terms of the dating of the right hand side IT diffusion determinants. As a result, we employ both.

A natural point of departure is the simple correlation between the flash density and the three IT measures for the 48 states in our sample. Figures 7 to 9 depict them.

>Figures 7 to 9 about here<

Visually, the strong negative correlations between the flash density and household and firm IT use, respectively, are unmistakable. By the middle of the first decade of the 21th century, states that experienced lightning strikes at a higher frequency also had relatively fewer users of computers and the Internet as well as lower IT investment intensity in manufacturing.

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[22] If IT is poorly measured this would also make it less likely that we can establish a link between lightning and IT. Measurement error (in this case) is found in the dependent variable, for which reason it will (under standard assumptions) inflate the standard errors of the estimated parameters. It thus becomes less likely to observe a statistically significant correlation with lightning activity.

A more systematic approach involves more controls. Human capital is probably the first additional determinant of diffusion that comes to mind. The idea that a more educated labor force is able to adopt new technologies more rapidly is an old one, going back at least to the work of Nelson and Phelps (1966). Another natural control is the level of GSP per worker. Aside from being a catch-all control for factors that facilitate diffusion, it can also be motivated as a measure of the "distance to the frontier". The sign of the coefficient assigned to GSP per worker is therefore ambiguous. A positive sign is expected if initially richer areas are able to acquire IT equipment more readily. A negative sign could arise if richer areas, by closer proximity to the technology frontier, are less able to capitalize on "advantages of backwardness".

In addition to labor productivity and human capital, we chiefly follow Caselli and Coleman (2001) in choosing relevant additional determinants of IT diffusion (they also include human capital and income per capita). First, we use measures for the composition of production; it seems plausible that IT may spread more rapidly in areas featuring manufacturing rather than agriculture. Second, we employ proxies for global links, measured by international movements of goods and capital, and a measure of local market size: state population. Third, we employ various historical variables as controls. Caselli and Coleman, studying cross-country data, include a measure of economic institutions, which we are not able to do directly in our US sample. However, by including various plausible historical determinants of productivity (e.g., soldier mortality, the pervasiveness of slavery in the late 19th century, etc.) we hope to pick up much the same type of information. Of course, in US cross-state data one expects differences in institutional quality to be a great deal smaller than what is typically found in cross-country data. Finally, moving beyond the "Caselli-Coleman controls", we examine the impact from the age structure of the population, religiousness, ethnic composition and urbanization on IT diffusion.[23]

In Table 10 we report baseline results for all three IT measures. In columns 1, 5 and 9 of the table we examine the simple correlations between the flash density and computer use, Internet use and manufacturing firms' IT investments, respectively. The lightning variable is

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[23] Details on all the data mentioned above are given in the Data Appendix.

always highly significant and it accounts for about 24% to 43% of the variation in the IT variables. In the remaining columns we add human capital controls and regional fixed effects progressively. Lightning is always highly significant, even with the inclusion of eight regional fixed effects. The only other variable that is consistently significant is the fraction of state population with a bachelor or higher; this is consistent with previous findings (e.g., Caselli and Coleman, 2001; Beaudry et al., 2006). It is also worth noting that we are able to span more than 80% of the variation in IT on the household side (columns 4 and 8) and more than 60% on the firm side (column 12).

Using the estimate from column 7 in Table 10 we find that a one standard deviation increase in lightning leads to a reduction in Internet users by about 1 percentage point.[24] In 2003 the states with the lowest Internet penetration (the 5th percentile) had about 44% of the population being able to access the Internet; at the other end of the spectrum (the 95th percentile) about 60% of the population was online. Hence the estimate for lightning implies that one standard deviation change in lightning can account for about 6% of the 95/5 gap; four standard deviations therefore motivates about 25% of the difference.

In an effort to check for robustness, Table 11 introduces additional controls to the long regressions in Table 10 (i.e., columns 4, 8 and 12), one by one. Nowhere is the influence from the flash density eliminated. Rather, the point estimate appears reasonably robust to the inclusion of alternative IT diffusion controls, economically as well as statistically.

>Table 11 about here<

The lightning-IT correlation can obviously not be ascribed to reverse causality. Moreover, since the remaining diffusion determinants are lagged, the risk that endogeneity of these variables is contaminating the OLS estimate for lightning is diminished. To be sure, it is impossible to completely rule out that the partial correlation between lightning and IT could be attributed to one or more omitted variables in the analysis above. Still, a causal interpretation is well founded on theoretical grounds: the empirical link between IT and

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[24] Recall, the standard deviation of the flash density variable is 2.4 in our 48 state sample.

lightning is clearly robust to a reasonable set of alternative IT determinants, and it is robust to regional fixed effects. Moreover, the point estimate seems stable across specifications. These characteristics provide a sound basis for believing the estimates above can be taken to imply that lightning is causally impacting on the speed of IT diffusion. We can, however, push the matter further on two accounts. First, we can ask whether IT can account for the link between growth and lightning. This is basically an indirect check of the exclusion restrict in an IV setup, where lightning serves as instrument for IT. Second, we can simply perform such an IV exercise.

Table 12 shows the relevant regression results; in columns 1-13 we address the first issue, while in columns 14 and 15 we address the second issue. Our focus is specifically on the 1991-2007 period, as this is the period during which lightning is significantly correlated with growth.

>Table 12 about here<

In column 1 of Table 12 the lightning-growth correlation is reproduced. In the following three columns we add the IT measures. Individually, all three are significantly and positively correlated with growth, as expected. The interpretation of the household IT variables is slightly different though. As noted above, the Internet originated in 1991. As a result, the independent variable can be seen as a proxy for Internet investments over the period; in 1991 the number of Internet users inevitably was close to zero, so the 2003 value effectively captures *changes* in Internet users over the relevant period. Needless to say the same is not true for computers, which started diffusing far earlier. If the IT investment rate is the relevant control, the computer variable is therefore measured with error. This may account for the fact that the economic size of the impact of the Internet variable is larger than that of computers in Table 12.

A key result of the exercise is reported in columns 5-7. When the IT variables are added to the equation, the flash density looses significance. The loss of significance is mainly attributable to a much lower point estimate; in column 7 it is reduced by almost a factor 7. A reasonable interpretation is that lightning appears in the growth regression due to its impact on IT diffusion. In columns 8-10 we include all four variables at once; in column 9 all human capital controls are also included, whereas in column 9 regional fixed effects are added to the list. Despite the obvious multicollinearity in this experiment, manufacturing firms' IT investment share remains strongly significant. This means that this latter variable dominates household's computer and Internet use as a predictor of US cross state real GSP growth rates in the Internet era: 1991 onwards. This continues to be the case when we exclude lightning, as done in columns 11-13.

In columns 14 and 15, we turn to an IV exercise using lightning as an instrument for manufacturing firms' IT investment share. In light of column 7, we have good reason to be optimistic that lightning satisfies the required exclusion restriction. In the IV regressions, we always include the human capital controls; in column 14 we include in addition the eight regional fixed effects.

Turning to the results, we first note that lightning is significant in the first stage in both columns. Moreover, the 2SLS point estimate is very similar to what is found using OLS. As expected, lightning is only a moderately strong instrument when the eight regions are included, as in column 14. However, the weak-instrument robust Stock-Wright (2000) S statistic, which tests the null that the coefficient of the endogenous regressor in the second stage is equal to zero, deems the IT variable significant. Moreover, since the regional fixed effects jointly are not even marginally significant, they can safely be excluded, in which case the lightning instrument becomes strong (first stage F > 10). Figure 10 provides a visual representation of the IV results.

>Figure 10 about here<

What is the economic significance of IT diffusion on growth? One approach would consist of studying the impact effect on growth from an increase in the intensity of IT investments. If we use the estimate from Table 12 (column 15) we find that a one percentage point increase in IT investment intensity increases growth – on impact – by about 0.15 percentage points. Of course, the initial growth impact should then drop off as the economy converges towards steady state.

Another approach to is to study the impact from greater IT investment intensity on the long run level of GDP per worker, rather than IT investments impact on transitional growth. Taking the IV estimate at face value (again Table 12, column 15), we find that an increase in IT expenditures as a fraction of total expenditures by 1 percent increases long-run labor productivity by about 0.6 percent.[25] Hence, our estimates suggest that IT indeed exerted a positive influence on growth, consistent with previous micro (firm) level estimates (e.g., Brynjolfsson and Hitt, 2003).

Overall, we believe the above analysis builds a fairly strong case in favor of the IT diffusion hypothesis; i.e., the thesis that lightning appears as a growth determinant in the 1990s due to the growing influence of digital technologies on economic growth.

4. Concluding Remarks

In theory, lightning should impact on IT diffusion. Higher lightning intensity leads to more frequent power disruptions, which in turn reduces the longevity of IT equipment. As a result, by inducing higher IT user cost, a higher lightning frequency should hamper IT investments. By implications, high-tech societies may actually be quite vulnerable to climate shocks. Consistent with the temperate drift hypothesis, technological change may therefore render societies more sensitive to climate phenomena that previously were only of second order importance.

Empirically, we document that lightning activity is negatively correlated with measures of IT diffusion; computers and Internet hook-ups per household and IT investment rates by manufacturing firms. Conditional on standard controls, states with less lightning have adopted IT more rapidly than states where lightning activity is more intensive.

Consistent with a detrimental impact on IT diffusion, we find that states with more lightning have grown slower from about 1990 onwards. This pattern cannot be accounted for by other

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[25] The implicit calculation proceeds as follows. Consider steady state where growth in GDP per worker is zero (or constant). Then we can work out the semi-elasticity of steady state GDP per worker with respect to IT investments as 0.15/1.25 = 0.12 (Table 12, column 15). Evaluated at the mean investment level (see Table 2), we then find the elasticity of roughly 0.6 (=0.12*5.4).

climate phenomena, nor can it be explained by a time varying influence from deep historical determinants of productivity.

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Data Appendix

Lightning. Our main measure of lightning density, originating from ground-based flash sensors, is from the US National Lightning Detection Network Database (NLDN). The NLDN consists of more than 100 remote, ground-based lightning sensors, which instantly detect the electromagnetic signals appearing when lightning strikes Earth's surface. The data is available as an average over the period 1996-2005 for the 48 contiguous US states from Vaisala's website: http://www.vaisala.com.

We find that lightning is not statistically different from a constant plus white noise (see main text for analysis). Therefore, we extend Vaisala's data to the period 1977-2007.

To investigate the time-series properties of lightning, we use data on the number of thunder days (TD) per year by state, available for the period 1901-1995. These data are collected as part of the Climate Change Detection and Attribution Program at the National Oceanic and Atmospheric Administration (NOAA). The raw data comes from 734 cooperative observer stations and 121 first order stations (see Changnon, 2001 for a detailed description). The data consists of monthly and yearly TD totals for 38 US states over the period 1901-1995, 40 states over the period 1906-1995 and 42 states over the period 1951-1995. It is available for purchase from the Midwestern Regional Climate Center:
http://mrcc.isws.illinois.edu/prod_serv/tstorm_cd/tstorm1.html.

From these data, we calculated the average yearly number of thunder days per state. Ultimately, we are interested in average *flash density* (FD) by state rather than thunder days per year. FDs are defined as the number of ground strikes per sq km per year. We converted yearly TDs into FDs using the following formula (Chisholm, 2000):

$$FD = 0.04 * TD^{1.25}$$

Temperature and Precipitation. Data from the United States Historical Climatology Network (USHCN) project, developed at NOAA's National Climatic Data Center (NCDC) to assist in the detection of regional climate change across the US. The USHCN project has produced a dataset of daily and monthly records of basic meteorological variables (maximum and minimum temperature, total precipitation, snowfall, and snow depth) from over 1000 stations across the 48 contiguous US states for the period 1900-2006.

The precipitation data we use is corrected by USHCN for the presence of outlier daily observations, time of data recording, and time series discontinuities due to random station moves and other station changes. The temperature data we use is additionally corrected for warming biases created by urbanization, and the replacement of liquid-in-glass thermometers by electronic temperature measurement devices during the mid 1980s.

We construct yearly average temperatures (expressed in degrees Celsius) and yearly average precipitation totals (expressed in cm per year) for each state, as simple averages of monthly data from 1221 stations across the country. The data is available at:
http://cdiac.ornl.gov/epubs/ndp/ushcn/newushcn.html.

Latitude. Latitude at the center of the state, calculated from geographic coordinates from the US Board on Geographic Names. The data is available at: http://geonames.usgs.gov/domestic/download_data.htm.

Altitude. Approximate mean elevation by state. Data source: US Geological Survey, Elevations and Distances in the United States, 1983. Available from the US Census Bureau at: http://www.census.gov/prod/2004pubs/04statab/geo.pdf.

Tornadoes, Wind, and Hail. The Storm Prediction Center of NOAA's National Weather Service Center provides data for tornadoes, wind, and hail for the period 1950-2007.

Data is available for the tornado occurrences and their damage categories in the Enhanced Fujita (EF) scale (assigning 6 levels from 0 to 5). We construct a measure of tornado intensity as the average damage category for all tornado occurrences during a year. For all the estimations, we rescale the EF categories from the original 0 to 5 scale to a 1 to 6 scale.

Wind is measured as the yearly average of wind speed, expressed in kilometers per hour.

Hail is measured as the average size of hail in centimeters.

The data is available at http://www.spc.noaa.gov/climo/historical.html.

Humidity, Sunshine and Cloudiness. Data from the "Comparative Climatic Data for the United States through 2007", published by NOAA.

(Relative) humidity is the average percentage amount of moisture in the air, compared to the maximum amount of moisture that the air can hold at the same temperature and pressure.

Cloudiness is measured as the average number of days per year with 8/10 to 10/10 average sky cover (or with 7/8 to 8/8 average sky cover since July 1996).

Sunshine is the total time that sunshine reaches the Earth's surface compared to the maximum amount of possible sunshine from sunrise to sunset with clear sky conditions.

The data is available at http://www1.ncdc.noaa.gov/pub/data/ccd-data/CCD-2007.pdf.

GSP per worker*.* Gross Domestic Product by state (GSP) per worker in chained 2000 US$.

US Bureau of Economic Analysis (BEA) offers two series of real GSP. The first is for the period 1977-1997, where industry classification is based on the Standard Industrial Classification (SIC) definitions. The second series covers the period 1997-2007 and relies on industrial classification based on the North American industrial Classification System (NAICS). Both GSP series are available at http://www.bea.gov/regional/gsp/.

We build a single measure of real GSP, extending levels of the series based on the SIC system with the yearly growth rates of the series based on the NAICS. This is equivalent to assuming

that from 1997 onwards, the growth rate of GSP per worker calculated with the SIC system equals the growth rate of real GSP calculated with the NAICS definitions.[26] Based on this estimate for real GSP, we construct a yearly series of real GSP per employed worker dividing real GSP by the number of employees per state. The growth rate is measured in percentages. State-by-state data for the number of employed workers is provided by the State Personal Income accounts at the US BEA (available at:
http://www.bea.gov/regional/spi).

Computers and Internet. Percentage of households with computer and percentage of households with Internet access at home in 2003. Data collected in a supplement to the October 2003 US Current Population Survey, available at:
http://www.census.gov/population/socdemo/computer/2003/tab01B.xls.

Manufacturing firms' IT investments. Capital expenditures on machinery and equipment for firms in the manufacturing sector are comprised by the following three categories: (1) Expenditures on automobiles, trucks, etc. for highway use. (2) Computers and peripheral data processing equipment. This item includes all purchases of computers and related equipment. (3) All other expenditures for machinery and equipment excluding automobiles and computer equipment. The variable we use is (2)/[(1)+(2)+(3)] ≡ Capital expenditures on computers and peripheral data processing equipment as a % of total capital expenditures on machinery and equipment of manufacturing firms. Data is from US Census Bureau, 2007 Economic Census. Detailed statistics for the manufacturing sector, by State, 2007 http://factfinder.census.gov/servlet/IBQTable?_bm=y&-geo_id=&-ds_name=EC0731A2&-_lang=en

Additional variables used in the paper

Variable	Definition and source
Human capital variables	This extended list of human capital variables is downloaded from www.allcountries.org.
Enrollment rate	Public elementary and secondary school enrollment as a percentage of persons 5-17 years old. From "Digest of Education Statistics", National Center of Education Statistics (NCES), Institute of Education Sciences, US Department of Education, http://nces.ed.gov/programs/digest/. Available at: http://www.allcountries.org/uscensus/266_public_elementary_and_secondary_school_enrollment.html.
High school degree or higher	Persons with a high school degree or higher as a percentage of persons 25 years and over. From "Digest of Education Statistics", National Center of Education Statistics (NCES), Institute of Education Sciences, US Department of Education, http://nces.ed.gov/programs/digest/d03/tables/dt011.asp.
Bachelor's degree or higher	Persons with a bachelor's degree or higher as a percentage of persons 25 years and over.

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[26] BEA warns against merging the *level* of the two series of real GSP directly, since the discontinuity in the industrial classification system will obviously affect level and growth rate estimates. Our choice of merging the *growth rates* of the two series can be justified recalling both the SIC and the NAICS aim to classify production of all industries in each state, so that the growth rate of both GSP series in levels is comparable. As a check, we computed the correlation between the growth rate of aggregate US GDP and gross domestic income (GDI), since GDP corresponds to the NAICS-definition and GDI corresponds to the SIC-definition (BEA, http://www.bea.gov/regional/gsp/). The correlation is higher than 0.99 for different periods between 1929 and 2007.

	Same source as high school degree or higher.
College degree or higher	Persons with a college degree or higher as a percentage of persons 25 years and over. Same source as high school degree or higher and bachelor's degree or higher.
Graduate or professional degree	Persons with a graduate or professional degree as a percentage of persons 25 years and over. Same source as high school degree or higher, bachelor's degree or higher, and college degree or higher.
Additional determinants of IT diffusion	In addition to human capital, Caselli and Coleman (2001) suggest the following set of determinants of computer technology diffusion across countries: real income, GDP shares of different sectors, stock of human capital, amount of trade, and degree of integration to the world economy. We gathered similar data for US states, described below.
Shares of agriculture production, manufacturing production, and government spending in GSP	Agriculture, forestry, fishing, and hunting production as % of GSP; Manufacturing production as % of GSP, Total Government spending as % of GSP. The 3 variables constructed from US BEA's data of GSP by industry, in millions of current US$. Available at: http://www.bea.gov/regional/gsp/.
Agricultural exports per capita	Agricultural exports per capita (US$). Total value of Agricultural exports by state, from US Department of Agriculture, divided by population. Available at: http://www.ers.usda.gov/Data/StateExports/2006/SXHS.xls Population data from US Census Bureau.
FDI per capita	Gross value of Property, Plant, and Equipment (PPE) of Nonbank US Affiliates, per capita (US$). Data on PPE available from US BEA for the period 1999-2006 available at: http://bea.doc.gov/international/xls/all_gross_ppe.xls. For the year 1981 and the period 1990-1997 available at: http://allcountries.org/uscensus/1314_foreign_direct_investment_in_the_u.html. Population data from US Census Bureau.
Institutional and historical determinants of productivity	All variables are taken from Mitchener and McClean (2003).
% workforce in mining, 1880	Percentage of the workforce employed in mining in 1880.
Average no. cooling degree days	The average number of cooling degree days is computed as the number of days in which the average air temperature rose above 65 degrees Fahrenheit (18 degrees Celsius) times the number of degrees on those days which the average daily air temperature exceeded 65 over the year.
% of 1860 population in slavery	The total number of slaves as a percentage of the total population of each state in 1860.
% of 1860 population on large slave plantations	The number of slaves owned by slaveholders having more than 20 slaves as a percentage of the total population of each state in 1860.
Access to navigable water	An indicator variable that takes the value of one if a state borders the ocean/Great Lake /river, and zero otherwise.
Settler origin	A series of indicator variables which take on positive values if a state, prior to statehood, had ties with that colonial power.
Average annual soldier mortality in 1829-1838, 1839-1854, %	Soldier mortality rates at the state level are derived using US soldier mortality data for individual forts. Quarterly data were collected by the US Surgeon General and Adjutant General's Offices 1829-1838 and by the US Surgeon General's Office for 1839-1854. Mitchener and McClean obtained the yearly mortality rates by dividing the number of deaths each year by the average annual "mean strength" of soldiers.
Socio-demographic indicators	Data on religiousness, race and ethnicity, urbanization and age structure of the population; from various sources.
Church attendance, average 2004-2006	Data from a Gallup Poll analysis, conducted between January 2004 and March 2006, based on responses to the question, "How often do you attend church or synagogue – at least once a week, almost every week, about once a month, seldom, or never?" Available at: http://www.gallup.com/poll/22579/church-attendance-lowestnew-england-highest-south.aspx#2
% of white population, black population, and	Data for race and Hispanic origin for the US, regions, divisions, and states (100-Percent Data). Source: US Census Bureau.

population of Hispanic origin	Available at: http://www.census.gov/population/www/documentation/twps0056/tabA-03.xls (for 1980), and http://www.census.gov/population/www/documentation/twps0056/tabA-01.xls (for 1990).
% of urban population	Rural and Urban population 1900-1990 (released 1995). Source: US Census Bureau. Available at: http://www.census.gov/population/www/censusdata/files/urpop0090.txt
% of population 15 years or less, and % of population between 15-64 years	Population by broad age group. “Demographic Trends in the 20th Century”, Table 7, parts D and E. Source: US Census Bureau. Available at: http://www.census.gov/prod/2002pubs/censr-4.pdf

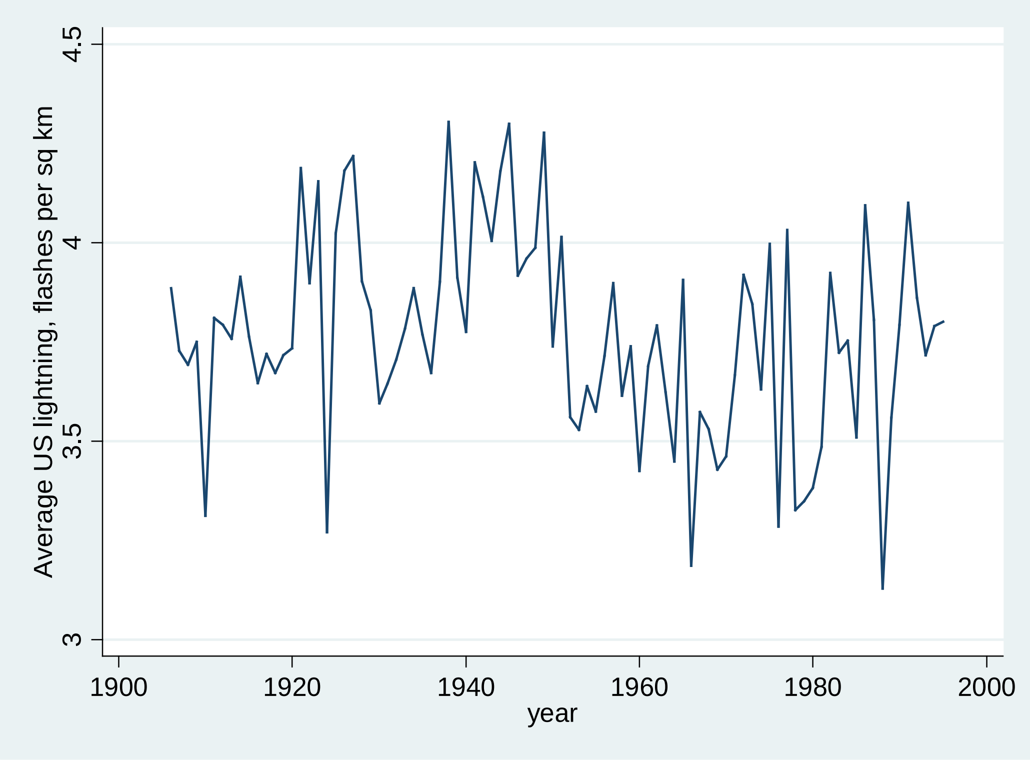


Figure 1. The average flash density in the US: 40 states

Source: Lightning observations from weather stations, transformed from thunder days (TD) into flash density (FD) using the formula FD = 0.04*TD1.25. See Data Appendix for details.

Notes: Only 40 states have complete information for the period 1906-1995. The "left-out" (contiguous) states are Connecticut, Delaware, New Hampshire, New Jersey, Rhode Island, Vermont, Mississippi, and West Virginia. The figure shows the weighted average, where the weight is determined by state size.

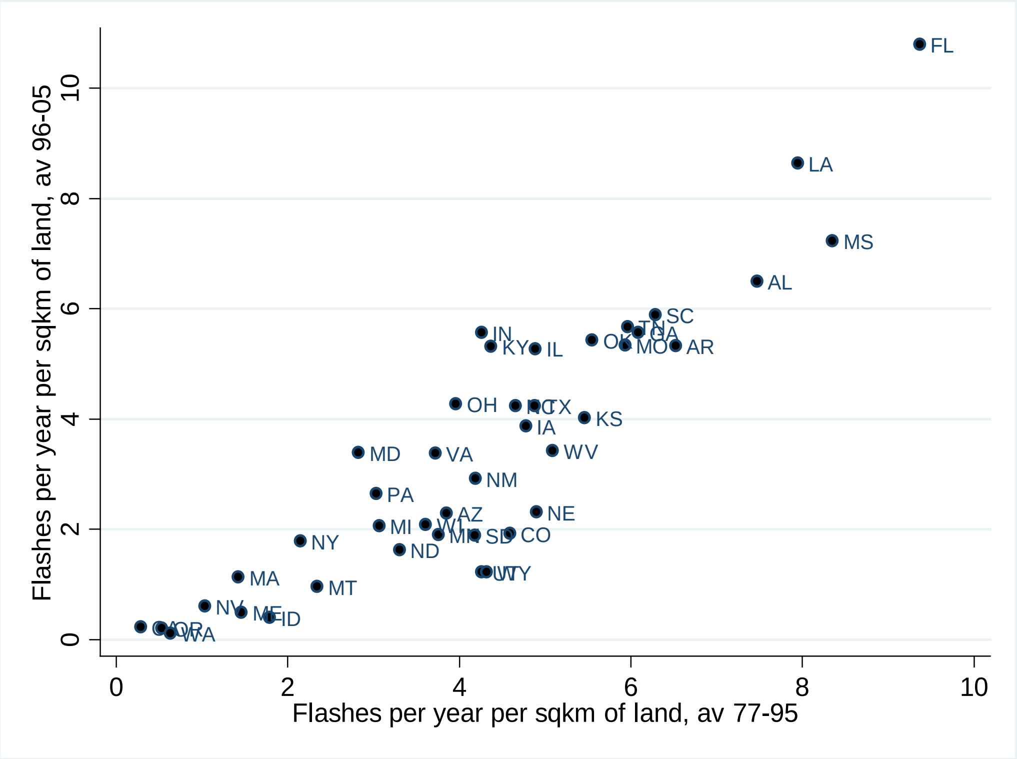


Figure 2. The average flash density 1977-95 versus 1996-2005: 42 states.

Sources: 1977-95 based on Thunder days (TD) from weather station observations, converted into flash density (FD) using the formula FD = 0.04*TD1.25. 1996-2005 data are based on ground detectors. See Appendix for further details.

Notes: The correlation is 0.90, and a regression, FL96-05 = a + bFL77-95 returns: a=-0.99, b=1.05, R2=0.81.

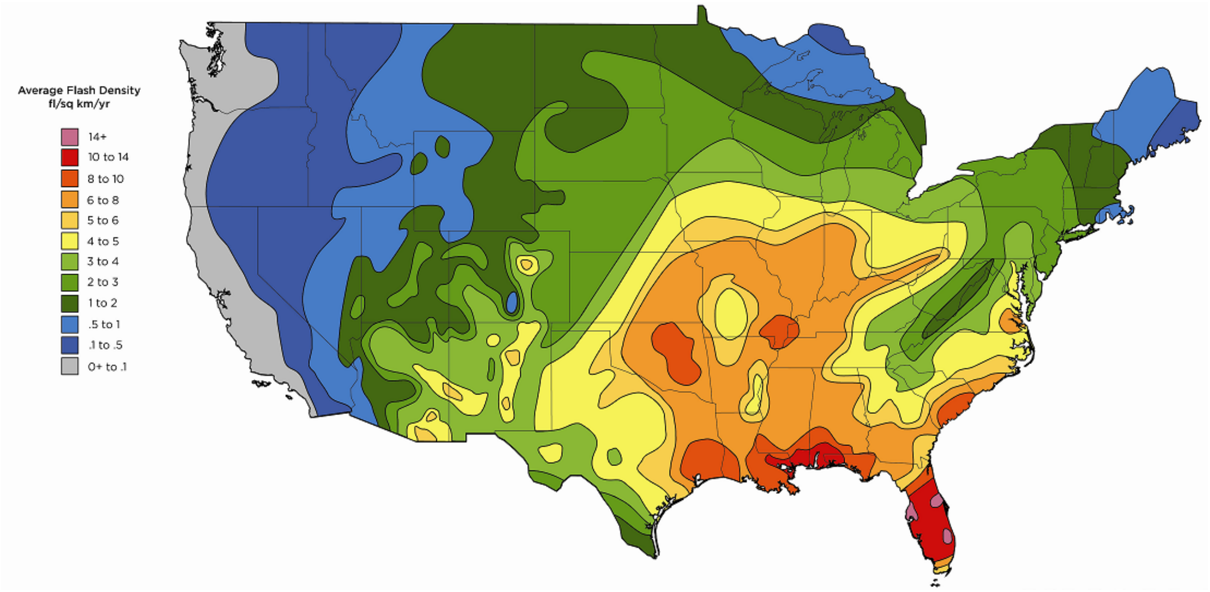
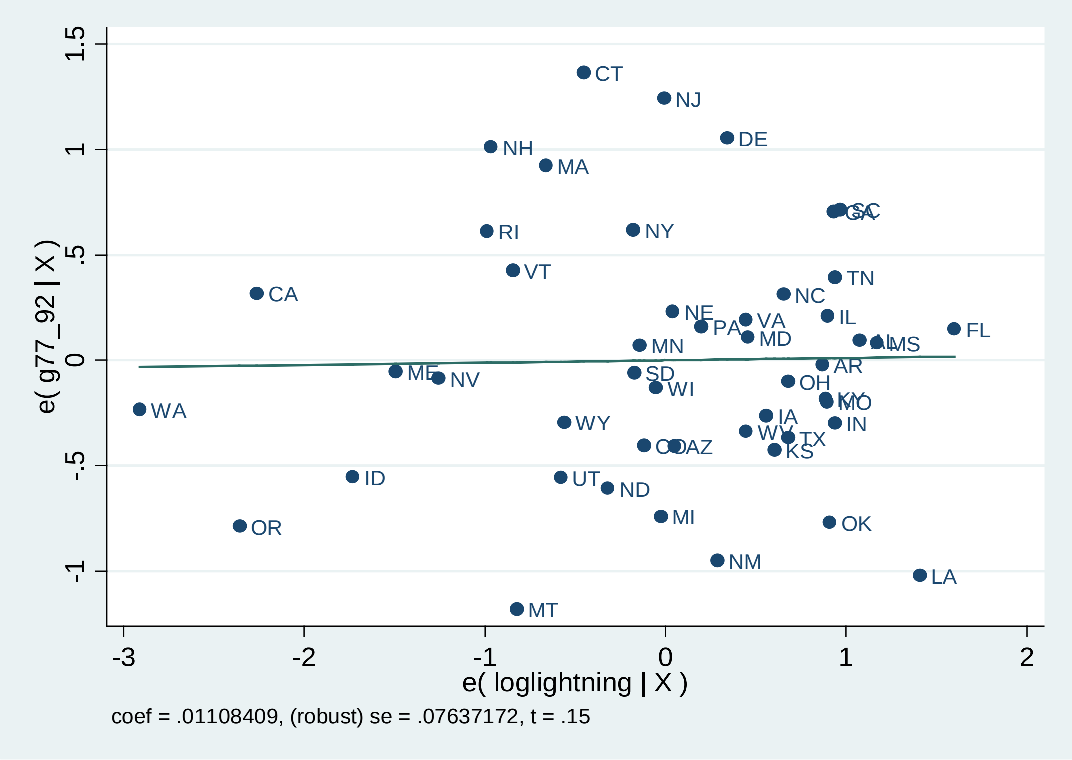
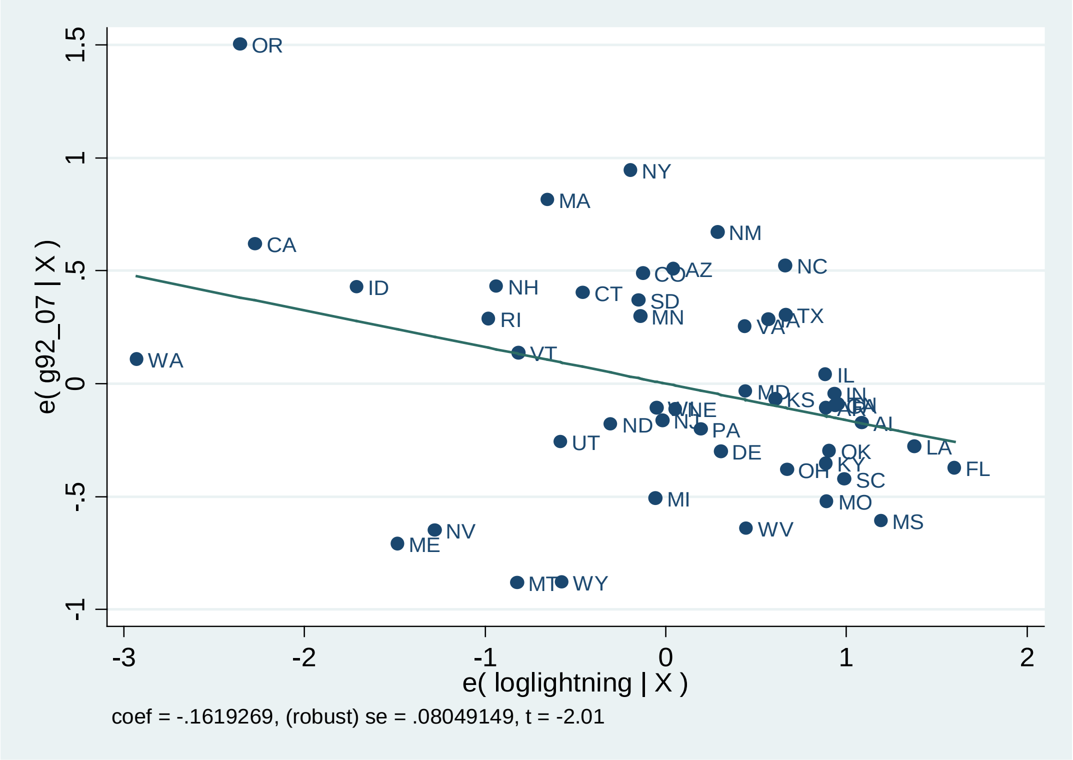


Figure 3. The distribution of flash densities across the US: 1996-2007.
Source: http://www.vaisala.com.



coef = .01108409, (robust) se = .07637172, t = .15

Figure 4. The correlation between state growth and (log) flash density, conditional on initial income per worker: 1977-1992.



coef = -.1619269, (robust) se = .08049149, t = -2.01

Figure 5. The correlation between state growth and (log) flash density, conditional on initial income per worker: 1992-2007.

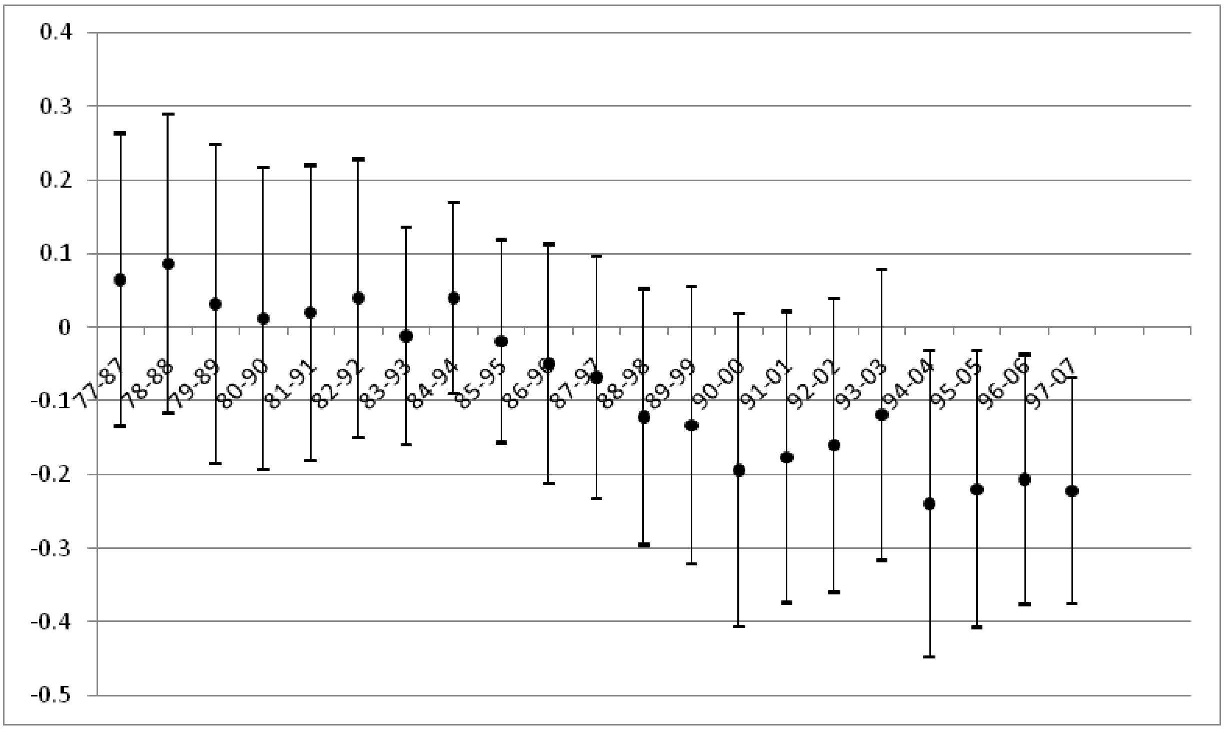


Figure 6. The lightning-growth nexus: 1977-2007.

Notes: The figure shows estimates for b2 (and the associated 95 percent confidence interval) from regressions of the form: $G = b_0 + b_1\log(y_{t-10})$+ b2log(lightning)+e, where y is gross state product per worker and t=1987,…,2007. 48 states; estimated by OLS.

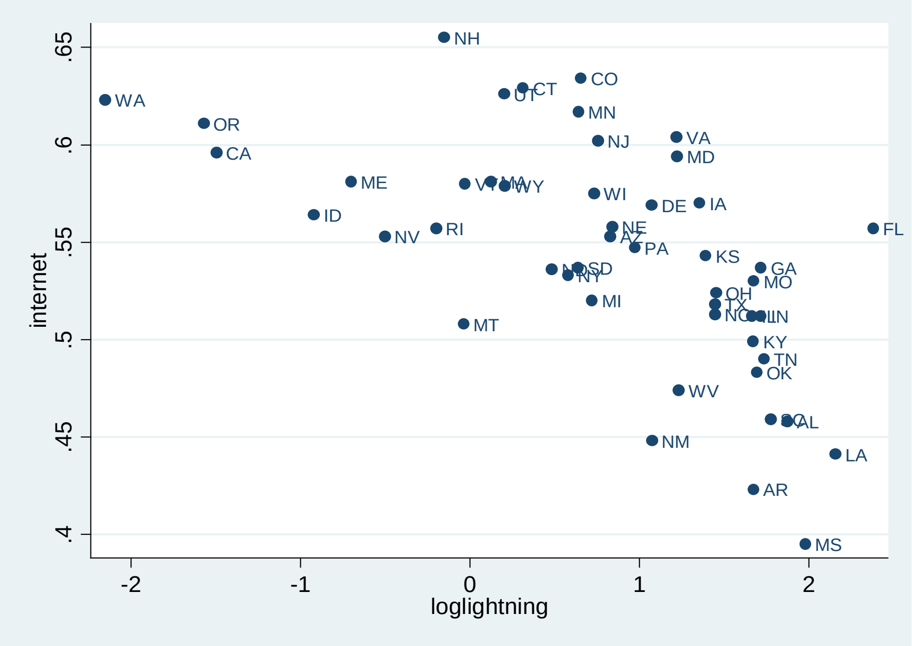


Figure 7. Lightning versus Internet users per 100 households in 2003.
Sources: See Data Appendix
Notes: The raw correlation between the two series is -0.62.

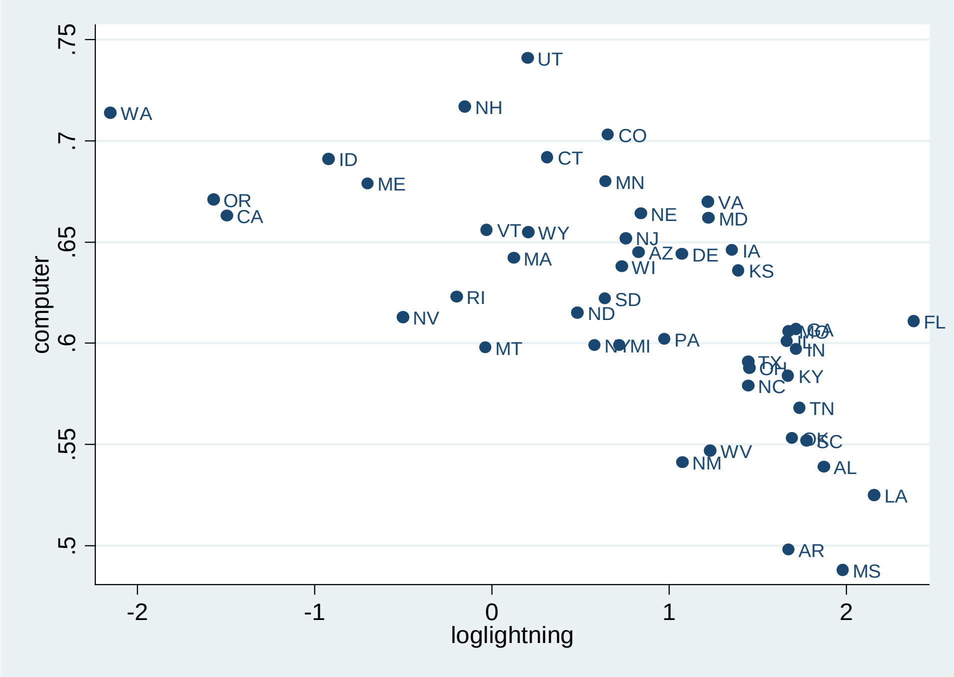


Figure 8. Lightning versus personal computers per 100 households in 2003.

Sources: See Data Appendix.

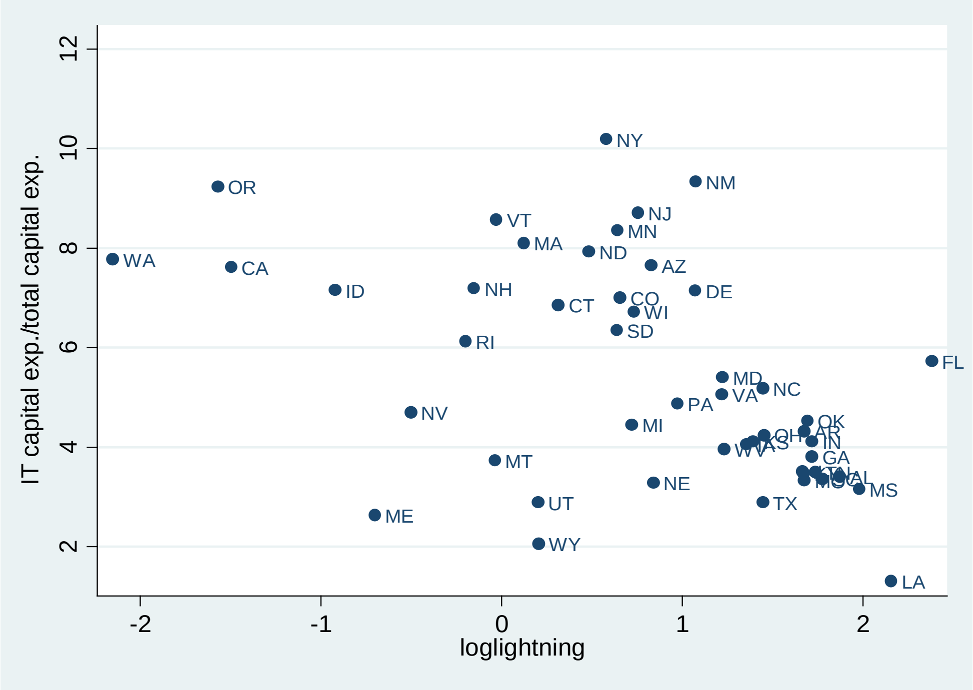


Figure 9. Lightning versus manufacturing firms' ICT capital expenditure to total capital expenditure.

Sources: See Data Appendix.

Notes: The raw correlation between the two series is -0.49.

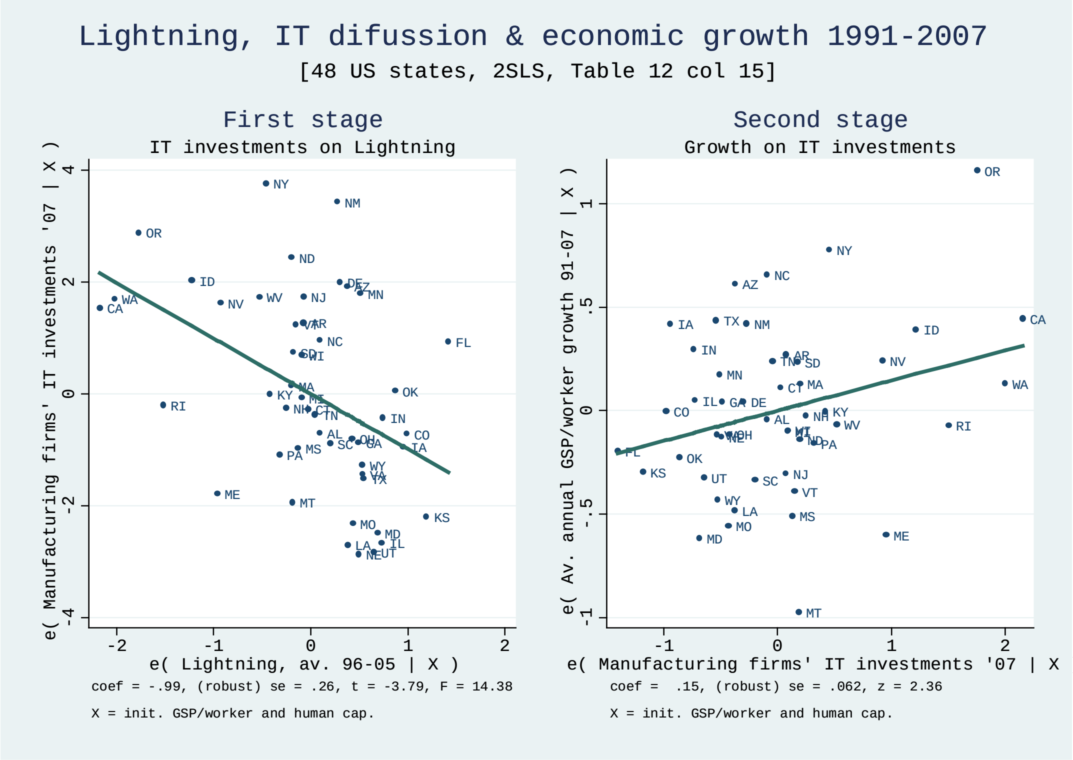


Figure 10. Exogenous component of manufacturing firms' ICT capital expenditure to total capital expenditure and economic growth, 1991-2007.

Sources: See Data Appendix.

Notes: Estimated by 2SLS.

Table 1. Dickey-Fuller tests for unit root in lightning

	test-statistic	p-value	No. obs.	No. lags
Aggregate US	-4.52	0.0000	88	1
Alabama	-5.31	0.0000	88	1
Arizona	-3.38	0.0118	87	2
Arkansas	-8.98	0.0000	89	0
California	-8.40	0.0000	89	0
Colorado	-8.69	0.0000	89	0
Florida	-8.19	0.0000	89	0
Georgia	-8.58	0.0000	89	0
Idaho	-3.48	0.0085	87	2
Illinois	-9.61	0.0000	89	0
Indiana	-8.24	0.0000	89	0
Iowa	-9.42	0.0000	89	0
Kansas	-4.46	0.0002	88	1
Kentucky	-2.94	0.0412	87	2
Louisiana	-4.62	0.0001	88	1
Maine	-2.75	0.0662	87	2
Maryland	-5.32	0.0000	88	1
Massachusetts	-9.25	0.0000	89	0
Michigan	-8.76	0.0000	89	0
Minnesota	-10.28	0.0000	89	0
Missouri	-9.92	0.0000	89	0
Montana	-9.01	0.0000	89	0
Nebraska	-3.64	0.0051	87	2
Nevada	-10.02	0.0000	89	0
New Mexico	-3.58	0.0062	87	2
New York	-4.01	0.0013	88	1
North Carolina	-5.40	0.0000	88	1
North Dakota	-7.84	0.0000	89	0
Ohio	-3.59	0.0059	87	2
Oklahoma	-11.61	0.0000	89	0
Oregon	-7.09	0.0000	89	0
Pennsylvania	-2.20	0.2045	86	3
South Carolina	-8.01	0.0000	89	0
South Dakota	-8.62	0.0000	89	0
Tennessee	-7.32	0.0000	89	0
Texas	-5.45	0.0000	88	1
Utah	-5.55	0.0000	88	1
Virginia	-7.41	0.0000	89	0
Washington	-8.75	0.0000	89	0
Wisconsin	-9.45	0.0000	89	0
Wyoming	-7.71	0.0000	89	0

Notes. The Augmented Dickey-Fuller test with no deterministic trend for each of the 40 states over the period 1906-1995. Lags selected by Schwarz's information criteria. Lightning is average number of flashes per year per square km, measured at weather stations.

Table 2. Summary statistics for the main variables

				Percentiles				
	Obs.	**Mean**	**Std. Dev.**	**99%**	**75%**	**50%**	**25%**	**1%**
Average annual growth rate of real GSP per worker (%):								
1977-1987	48	0.81	0.77	2.69	1.32	0.74	0.30	-0.76
1987-1997	48	1.21	0.58	2.67	1.50	1.22	0.82	-0.32
1997-2007	48	1.18	0.54	2.59	1.49	1.15	0.74	0.26
1977-2007	48	1.07	0.42	1.97	1.37	1.07	0.82	0.10
1991-2007	48	1.34	0.50	2.79	1.71	1.35	1.01	0.29
Lightning density, average 1996-2005 (flashes/year/sq km)	48	3.18	2.39	10.8	5.30	2.48	1.23	0.12
Manufacturing firms' IT investments, 2007 (% of non-construction capital expenditures)	48	5.40	2.20	10.19	7.17	4.78	3.51	1.31
Access to Internet at home, 2003 (% of households)	48	54.39	5.88	65.50	58.10	55.00	51.20	39.50
Computer at home, 2003 (% of households)	48	62.10	5.71	74.10	66.25	61.85	58.95	48.80

Notes. Lightning defined as average number of flashes per year per square km over the period 1995-2006, measured by flash-detectors. IT capital expenditures defined as capital expenditures on computers and peripheral data processing equipment in all manufactuting firms in 2007, expressed as a percentage of all non-construction capital expenditures. Data sources and extended definitions are provided in the Data appendix.

Table 3. Growth and lightning

(1)	5-year periods	**1977-1982**	**1982-1987**	**1987-1992**	**1992-1997**	**1997-2002**	**2002-2007**	Observations	R-squared
		-0.04	0.17	-0.09	-0.04	-0.28**	-0.18*	288	0.20
		[0.10]	[0.16]	[0.09]	[0.12]	[0.11]	[0.09]		

(2)	10-year periods	**1977-1987**	**1987-1997**	**1997-2007**	Observations	R-squared
		0.07	-0.07	-0.22***	144	0.15
		[0.10]	[0.08]	[0.08]		

(3)	15-year periods	**1977-1992**	**1992-2007**	Observations	R-squared
		0.01	-0.16**	96	0.20
		[0.08]	[0.08]		

Notes. Pooled OLS estimates of the coefficient on lightning (b_{2t}). The dependent variable in regressions (1), (2) and (3) is the yearly average growth rate in GSP per worker over periods of 5, 10, and 15 years, respectively. All regressions include a constant, the initial level of (log) real GSP per worker and a full set of time-dummies. Lightning is the average number of flashes per year per square km, measured by flash-detectors. Robust standard errors in brackets, adjusted for clustering at state level. Asterisks ***, **, and * indicate significance at the 1, 5, and 10%, respectively.

Table 4. Growth and lightning - controlling for human capital and regional fixed effects

Dependent variable:	Average annual growth in GSP per worker over periods of 10 years (1977 - 1987, 1987 - 1997, 1997 - 2007)					
	(1)	(2)	(3)	(4)	(5)	(6)
(log, initial) Real GSP per worker	-0.72	-1.24***	-0.60	-1.25***	-1.80***	-1.97***
	[0.45]	[0.41]	[0.46]	[0.44]	[0.41]	[0.54]
(log) Lightning × t_{77-87}	0.07	-0.04	-0.14	0.13	-0.12	-0.04
	[0.10]	[0.11]	[0.12]	[0.11]	[0.11]	[0.15]
(log) Lightning × t_{87-97}	-0.07	-0.16**	-0.07	0.03	-0.12	-0.05
	[0.08]	[0.07]	[0.09]	[0.08]	[0.08]	[0.14]
(log) Lightning × t_{97-07}	-0.22***	-0.24***	-0.22**	-0.13*	-0.21**	-0.17
	[0.08]	[0.08]	[0.09]	[0.08]	[0.08]	[0.14]
(initial) Enrollment rate × t_{77-87}		-0.07***			-0.06***	-0.04*
		[0.02]			[0.02]	[0.02]
(initial) Enrollment rate × t_{87-97}		-0.07***			-0.07***	-0.05*
		[0.02]			[0.02]	[0.03]
(initial) Enrollment rate × t_{97-07}		-0.03			-0.01	0.01
		[0.02]			[0.02]	[0.02]
(initial) High school degree or higher × t_{77-87}			-0.04***		-0.06***	-0.05***
			[0.01]		[0.02]	[0.02]
(initial) High school degree or higher × t_{87-97}			-0.0016		-0.02	-0.01
			[0.015]		[0.02]	[0.02]
(initial) High school degree or higher × t_{97-07}			-0.00076		-0.05**	-0.03
			[0.019]		[0.02]	[0.03]
(initial) Bachelor's degree or higher × t_{77-87}				0.18	0.51***	0.50***
				[0.16]	[0.16]	[0.15]
(initial) Bachelor's degree or higher × t_{87-97}				0.06**	0.07**	0.06
				[0.02]	[0.03]	[0.04]
(initial) Bachelor's degree or higher × t_{97-07}				0.07***	0.10***	0.09***
				[0.01]	[0.02]	[0.02]
Observations	144	144	144	144	144	144
R-squared	0.15	0.28	0.20	0.24	0.44	0.47
Regional fixed effects (8 BEA economic areas)	No	No	No	No	No	Yes
Joint significance tests (p values):						
H_0: Regional FEs = 0	.	.	.	.	.	0.79
H_0: Regional FEs and lightning terms = 0	.	.	.	.	.	0.0065

Notes. Pooled OLS estimates. The dependent variable is the yearly growth rate of GSP per worker over the periods 1977-1987, 1987-1997, and 1997-2007. Lightning is the average number of flashes per year per square km, measured by flash-detectors. The different proxies for human capital are described in the appendix, and measured at the beginning of each 10-year period (1977, 1987 and 1997), except for enrollment rates (measured in 1980 instead of 1977 for the first period) and the % of population with a highschool degree or higher (measured in 1980, 1990 and 2000 instead of 1977, 1987 and 1997 for each respective period), due to data availability. The set of regional fixed effects in column (6) accounts for the 8 US Bureau of Economic Analysis' economic areas. All regressions include a constant and a full set of time-dummies. Robust standard errors in brackets, adjusted for clustering at the state level. Asterisks ***, **, and * indicate significance at the 1, 5, and 10%, respectively.

Table 5. Growth regressions with lightning and other geographical and climate variables

Dependent variable:	Average annual growth in GSP per worker over periods of 10 years (1977-1987, 1987-1997, 1997-2007)										
GEOGRAPHY:		Temperature (C degrees)	Precipitation (cm/year)	Tornado intensity (av EF-scale)	Hail size (cm)	Wind speed (km/h)	Humidity (% moisture in air)	Cloudiness (days/year)	Sunshine (days/year)	Elevation (meters above sea level)	Latitude (degrees)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(log, initial) Real GSP per worker	-1.80***	-1.71***	-1.82***	-1.83***	-2.01***	-1.83***	-1.76***	-1.73***	-1.93***	-1.81***	-1.72***
	[0.41]	[0.39]	[0.45]	[0.45]	[0.42]	[0.44]	[0.42]	[0.41]	[0.47]	[0.43]	[0.40]
(log) Lightning × $t_{77\text{-}87}$	-0.12										
	[0.11]										
(log) Lightning × $t_{87\text{-}97}$	-0.12										
	[0.08]										
(log) Lightning × $t_{97\text{-}07}$	-0.21**										
	[0.08]										
(log) GEOGRAPHY × $t_{77\text{-}87}$		-0.38	0.77*	1.11*	-1.36**	-0.41*	1.08	0.76	-0.91	-0.31**	1.07
		[0.26]	[0.41]	[0.60]	[0.66]	[0.20]	[1.05]	[0.50]	[0.67]	[0.13]	[0.93]
(log) GEOGRAPHY × $t_{87\text{-}97}$		0.31	0.14	0.082	-0.086	0.063	-1.06	-0.25	0.028	0.13	-0.34
		[0.29]	[0.39]	[0.48]	[0.71]	[0.11]	[0.88]	[0.42]	[0.50]	[0.093]	[0.99]
(log) GEOGRAPHY × $t_{97\text{-}07}$		-0.033	0.042	-0.25	-1.79*	0.32	-0.38	-0.11	-0.09	0.13	0.95
		[0.35]	[0.19]	[0.22]	[0.95]	[0.32]	[0.59]	[0.34]	[0.48]	[0.087]	[0.80]
Observations	144	144	144	144	144	144	144	144	141	144	144
R-squared	0.44	0.42	0.43	0.43	0.44	0.43	0.42	0.42	0.42	0.46	0.42
Human capital controls (enrollment, high school or higher, BA)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes. Pooled OLS estimates. The dependent variable is the annual growth rate in GSP per worker over the periods 1977-1987, 1987-1997 and 1997-2007. All regressions include a constant and a full set of time-dummies. Lightning is the average number of flashes per year per square km, measured by flash-detectors. The controls for human capital are the initial enrollment rate, percentage of population with a high school or higher degree, and percentage of population with a BA degree. All the human capital controls are measured at the beginning of each 10-year period (1977, 1987 and 1997), except for enrollment rates (measured in 1980 instead of 1977) and the % of population with a highschool degree or higher (measured in 1980, 1990 and 2000 instead of 1977, 1987 and 1997), due to data availability. All geographic/climate variables are averages taken over periods of 10 years. Robust standard errors in brackets, adjusted for clustering at state level. Asterisks ***, **, and * indicate significance at the 1, 5, and 10%, respectively.

Table 6. Growth regressions with lightning and geographical and climate controls

Dependent variable:	Average annual growth in GSP per worker over periods of 10 years (1977-1987, 1987-1997, 1997-2007)										
GEOGRAPHY:		Temperature (C degrees)	Precipitation (cm/year)	Tornado intensity (av EF-scale)	Hail size (cm)	Wind speed (km/h)	Humidity (% moisture in air)	Cloudiness (days/year)	Sunshine (days/year)	Elevation (meters above sea level)	Latitude (degrees)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(log, initial) Real GSP per worker	-1.80***	-1.80***	-1.85***	-1.85***	-1.96***	-1.84***	-1.78***	-1.77***	-1.98***	-1.86***	-1.81***
	[0.41]	[0.37]	[0.44]	[0.42]	[0.43]	[0.42]	[0.41]	[0.39]	[0.44]	[0.41]	[0.38]
(log) Lightning × t_{77-87}	-0.12	-0.085	-0.07	-0.13	-0.048	-0.19	-0.12	-0.059	-0.07	-0.16	-0.07
	[0.11]	[0.11]	[0.11]	[0.11]	[0.11]	[0.12]	[0.11]	[0.12]	[0.11]	[0.11]	[0.13]
(log) Lightning × t_{87-97}	-0.12	-0.16*	-0.11	-0.12	-0.13	-0.11	-0.11	-0.15	-0.14	-0.098	-0.20*
	[0.08]	[0.096]	[0.085]	[0.084]	[0.085]	[0.086]	[0.089]	[0.10]	[0.095]	[0.084]	[0.12]
(log) Lightning × t_{97-07}	-0.21**	-0.24***	-0.21**	-0.20**	-0.20**	-0.20**	-0.21**	-0.21***	-0.22***	-0.19**	-0.23**
	[0.08]	[0.078]	[0.079]	[0.079]	[0.086]	[0.083]	[0.084]	[0.077]	[0.077]	[0.081]	[0.095]
(log) GEOGRAPHY × t_{77-87}		-0.31	0.73*	1.14*	-1.24*	-0.49**	1.01	0.67	-0.76	-0.34***	0.76
		[0.28]	[0.39]	[0.61]	[0.69]	[0.20]	[1.06]	[0.51]	[0.66]	[0.11]	[1.05]
(log) GEOGRAPHY × t_{87-97}		0.44	0.10	0.17	0.23	0.055	-1.00	-0.42	0.28	0.11	-1.26
		[0.28]	[0.39]	[0.51]	[0.75]	[0.11]	[0.84]	[0.46]	[0.52]	[0.097]	[1.22]
(log) GEOGRAPHY × t_{97-07}		0.30	0.06	-0.13	-0.28	0.16	0.0031	-0.23	0.15	0.065	-0.43
		[0.39]	[0.19]	[0.21]	[0.81]	[0.29]	[0.73]	[0.28]	[0.36]	[0.082]	[0.95]
Observations	144	144	144	144	144	144	144	144	141	144	144
R-squared	0.44	0.46	0.47	0.47	0.46	0.47	0.45	0.46	0.46	0.49	0.45
Human capital controls (enrollment, high school or higher, BA)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes. Pooled OLS estimates. The dependent variable is the annual growth rate in GSP per worker over the periods 1977-1987, 1987-1997 and 1997-2007. All regressions include a constant and a full set of time-dummies. Lightning is the average number of flashes per year per square km, measured by flash-detectors. The controls for human capital are the initial enrollment rate, percentage of population with a high school or higher degree, and percentage of population with a BA degree. All the human capital controls are measured at the beginning of each 10-year period (1977, 1987 and 1997), except for enrollment rates (measured in 1980 instead of 1977) and the % of population with a highschool degree or higher (measured in 1980, 1990 and 2000 instead of 1977, 1987 and 1997), due to data availability. All geographic/climate variables are averages taken over periods of 10 years. Robust standard errors in brackets, adjusted for clustering at state level. Asterisks ***, **, and * indicate significance at the 1, 5, and 10%, respectively.

Table 7. Growth regressions with historical controls (geography and institutions)

Dependent variable:	Average annual growth in GSP per worker over periods of 10 years (1977-1987, 1987-1997, 1997-2007)										
HISTORY:		% of workforce in mining, 1880	Average no. of cooling degree days	% of 1860 population in slavery	Access to navigable water	% of 1860 population on large slave plantations	Settler origin: English	Settler origin: French	Settler origin: Spanish	Settler origin: Dutch	Average annual soldier mortality in 1829-1838, 1839-1854, %
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(log, initial) Real GSP per worker	-1.80***	-1.77***	-1.75***	-1.82***	-1.89***	-1.82***	-1.70***	-2.07***	-1.70***	-1.85***	-1.59***
	[0.41]	[0.43]	[0.41]	[0.42]	[0.46]	[0.42]	[0.40]	[0.34]	[0.40]	[0.44]	[0.42]
(log) Lightning × t_{77-87}	-0.12										
	[0.11]										
(log) Lightning × t_{87-97}	-0.12										
	[0.08]										
(log) Lightning × t_{97-07}	-0.21**										
	[0.08]										
HISTORY × t_{77-87}		-0.015*	-0.017*	0.0020	0.49	0.0041	0.49***	-0.33*	-0.45***	0.30	-0.20**
		[0.0082]	[0.0092]	[0.0065]	[0.31]	[0.010]	[0.17]	[0.16]	[0.17]	[0.22]	[0.097]
HISTORY × t_{87-97}		-0.0011	-0.0075	-0.0094	0.23	-0.017**	-0.022	-0.50***	-0.11	0.075	-0.017
		[0.010]	[0.0093]	[0.0058]	[0.31]	[0.0083]	[0.19]	[0.15]	[0.16]	[0.25]	[0.098]
HISTORY × t_{97-07}		0.0078	-0.00097	-0.0097*	0.15	-0.014*	-0.14	-0.18	0.092	0.22	-0.19*
		[0.0061]	[0.011]	[0.0049]	[0.17]	[0.0071]	[0.17]	[0.13]	[0.15]	[0.29]	[0.10]
Observations	144	144	144	144	144	144	144	144	144	144	144
R-squared	0.44	0.42	0.42	0.43	0.43	0.43	0.45	0.46	0.44	0.41	0.43
Human capital controls (enrollment, high school or higher, BA)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes. Pooled OLS estimates. The dependent variable is the annual growth rate of GSP per worker over the periods 1977-1987, 1987-1997 and 1997-2007. All regressions include a constant and a full set of time-dummies. Lightning is the average number of flashes per year per square km, measured by flash-detectors. The controls for human capital are the initial enrollment rate, percentage of population with a high school or higher degree, and percentage of population with a BA degree. All the human capital controls are measured at the beginning of each 10-year period (1977, 1987 and 1997), except for enrollment rates (measured in 1980 instead of 1977) and the % of population with a highschool degree or higher (measured in 1980, 1990 and 2000 instead of 1977, 1987 and 1997), due to data availability. HISTORY controls taken from Mitchener and McLean (2004). Robust standard errors in brackets, adjusted for clustering at state level. Asterisks ***, **, and * indicate significance at the 1, 5, and 10%, respectively.

Table 8. Growth regressions with lightning and historical controls (geography and institutions)

Dependent variable:	Average annual growth in GSP per worker over periods of 10 years (1977-1987, 1987-1997, 1997-2007)										
HISTORY:		% of workforce in mining, 1880	Average no. of cooling degree days	% of 1860 population in slavery	Access to navigable water	% of 1860 population on large slave plantations	Settler origin: English	Settler origin: French	Settler origin: Spanish	Settler origin: Dutch	Average annual soldier mortality in 1829-1838, 1839-1854, %
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(log, initial) Real GSP per worker	-1.80***	-1.80***	-1.76***	-1.80***	-1.92***	-1.79***	-1.73***	-2.03***	-1.73***	-1.86***	-1.65***
	[0.41]	[0.42]	[0.40]	[0.41]	[0.44]	[0.41]	[0.39]	[0.35]	[0.39]	[0.42]	[0.40]
(log) Lightning × t_{77-87}	-0.12	-0.14	-0.051	-0.14	-0.10	-0.14	-0.098	-0.072	-0.10	-0.11	-0.087
	[0.11]	[0.12]	[0.12]	[0.12]	[0.12]	[0.12]	[0.10]	[0.12]	[0.10]	[0.11]	[0.11]
(log) Lightning × t_{87-97}	-0.12	-0.12	-0.11	-0.072	-0.12	-0.067	-0.12	-0.047	-0.11	-0.12	-0.12
	[0.08]	[0.083]	[0.092]	[0.10]	[0.086]	[0.100]	[0.085]	[0.11]	[0.084]	[0.083]	[0.089]
(log) Lightning × t_{97-07}	-0.21**	-0.20**	-0.28***	-0.18*	-0.22***	-0.19**	-0.20***	-0.20**	-0.20**	-0.21**	-0.18**
	[0.08]	[0.089]	[0.079]	[0.092]	[0.079]	[0.089]	[0.076]	[0.092]	[0.077]	[0.080]	[0.088]
HISTORY × t_{77-87}		-0.016**	-0.015	0.0042	0.47	0.0068	0.48***	-0.29	-0.44**	0.28	-0.18*
		[0.0079]	[0.0098]	[0.0075]	[0.30]	[0.011]	[0.17]	[0.20]	[0.17]	[0.23]	[0.097]
HISTORY × t_{87-97}		-0.0035	-0.0017	-0.0076	0.23	-0.015	-0.022	-0.48***	-0.10	0.037	0.016
		[0.010]	[0.0092]	[0.0070]	[0.31]	[0.0096]	[0.19]	[0.18]	[0.16]	[0.25]	[0.10]
HISTORY × t_{97-07}		0.0015	0.017***	-0.0044	0.21	-0.0065	-0.10	-0.055	0.065	0.19	-0.12
		[0.0065]	[0.0058]	[0.0056]	[0.17]	[0.0079]	[0.14]	[0.15]	[0.13]	[0.27]	[0.12]
Observations	144	144	144	144	144	144	144	144	144	144	144
R-squared	0.44	0.46	0.46	0.45	0.47	0.46	0.48	0.48	0.48	0.45	0.46
Human capital controls (enrollment, high school or higher, BA)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes. Pooled OLS estimates. The dependent variable is the annual growth rate of GSP per worker over the periods 1977-1987, 1987-1997 and 1997-2007. All regressions include a constant and a full set of time-dummies. Lightning is the average number of flashes per year per square km, measured by flash-detectors. The controls for human capital are the initial enrollment rate, percentage of population with a high school or higher degree, and percentage of population with a BA degree. All the human capital controls are measured at the beginning of each 10-year period (1977, 1987 and 1997), except for enrollment rates (measured in 1980 instead of 1977) and the % of population with a highschool degree or higher (measured in 1980, 1990 and 2000 instead of 1977, 1987 and 1997), due to data availability. HISTORY controls taken from Mitchener and McLean (2004). Robust standard errors in brackets, adjusted for clustering at state level. Asterisks ***, **, and * indicate significance at the 1, 5, and 10%, respectively.

Table 9. Growth regressions with lightning and trade & integration controls

Dependent variable:	Average annual growth in GSP per worker over periods of 10 years (1977-1987, 1987-1997, 1997-2007)				
INTEGRATION:		Agricultural exports per capita	FDI per capita	Agricultural exports per capita	FDI per capita
	(1)	(2)	(3)	(4)	(5)
(log, initial) Real GSP per worker	-1.80***	-1.81***	-1.78***	-1.82***	-1.79***
	[0.41]	[0.38]	[0.51]	[0.38]	[0.50]
(log) Lightning × $t_{77\text{-}87}$	-0.12			-0.023	-0.12
	[0.11]			[0.11]	[0.11]
(log) Lightning × $t_{87\text{-}97}$	-0.12			-0.082	-0.12
	[0.08]			[0.088]	[0.085]
(log) Lightning × $t_{97\text{-}07}$	-0.21**			-0.24***	-0.21***
	[0.08]			[0.067]	[0.077]
(log) INTEGRATION × $t_{77\text{-}87}$		-0.13**	0.023	-0.13**	0.034
		[0.048]	[0.15]	[0.051]	[0.15]
(log) INTEGRATION × $t_{87\text{-}97}$		-0.094	0.11	-0.08	0.11
		[0.057]	[0.18]	[0.063]	[0.17]
(log) INTEGRATION × $t_{97\text{-}07}$		0.065	-0.17	0.10**	-0.19
		[0.040]	[0.13]	[0.039]	[0.13]
Observations	144	144	144	144	144
R-squared	0.44	0.46	0.41	0.49	0.45
Human capital controls (enrollment, high school or higher, BA)	Yes	Yes	Yes	Yes	Yes

Notes. Pooled OLS estimates. The dependent variable is the annual growth rate of GSP per worker over the periods 1977-1987, 1987-1997 and 1997-2007. All regressions include a constant and a full set of time-dummies. Lightning is the average number of flashes per year per square km, measured by flash-detectors. The controls for human capital are the initial enrollment rate, percentage of population with a high school or higher degree, and percentage of population with a BA degree. All the human capital controls are measured at the beginning of each 10-year period (1977, 1987 and 1997), except for enrollment rates (measured in 1980 instead of 1977) and the % of population with a highschool degree or higher (measured in 1980, 1990 and 2000 instead of 1977, 1987 and 1997), due to data availability. Robust standard errors in brackets, adjusted for clustering at state level. Asterisks ***, **, and * indicate significance at the 1, 5, and 10%, respectively.

Table 10. Lightning and IT diffusion

Dependent variable:	% of households with a personal computer at home, 2003				% of households with Internet access at home, 2003				Manufacturing firms' IT investments, 2007			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(log) Lightning	-3.68***	-3.68***	-1.15***	-2.66***	-3.57***	-3.57***	-1.14***	-1.69*	-1.06***	-1.06***	-0.99***	-1.69**
	[0.56]	[0.58]	[0.38]	[0.80]	[0.61]	[0.62]	[0.41]	[0.88]	[0.23]	[0.24]	[0.26]	[0.64]
(log) Real GSP per worker, 1991		5.57*	1.96	4.64		9.95***	4.83	5.32		1.39	-3.31	-4.05*
		[3.26]	[2.85]	[3.19]		[3.46]	[2.97]	[3.70]		[1.92]	[2.00]	[2.37]
Enrollment rate, 1991			0.066	0.037			-0.0054	0.05			-0.20***	-0.17
			[0.097]	[0.20]			[0.092]	[0.22]			[0.066]	[0.14]
High school degree or higher, 1990			0.60***	0.76***			0.53***	0.77***			-0.091	0.014
			[0.11]	[0.15]			[0.11]	[0.19]			[0.058]	[0.12]
Bachelor's degree or higher, 1991			0.35**	0.30**			0.45***	0.39**			0.32***	0.29**
			[0.15]	[0.13]			[0.15]	[0.17]			[0.073]	[0.14]
Observations	48	48	48	48	48	48	48	48	48	48	48	48
R-squared	0.43	0.45	0.79	0.84	0.38	0.45	0.77	0.82	0.24	0.25	0.50	0.63
Regional fixed effects (8 BEA economic areas)	No	No	No	Yes	No	No	No	Yes	No	No	No	Yes
H_0: Regional FEs = 0 (p value)	.	.	.	0.02	.	.	.	0.28	.	.	.	0.09

Notes. OLS estimates. The dependent variables are (a) the percentage of household with access to a personal computer at home in 2003, (b) the % of households with access to Internet at home, and (c) the level of IT investments in the manufacturing sector, measured as the amount capital expenditures on computers and peripheral data processing equipment, relative to all non-construction capital expenditures, respectively. Lightning is the average number of flashes per year per square km, measured by flash-detectors. The rest of the covariates are described in the Data Appendix. Robust standard errors in brackets. Asterisks ***, **, and * indicate significance at the 1, 5, and 10%, respectively.

Table 11. Lightning and IT diffusion - Additional controls

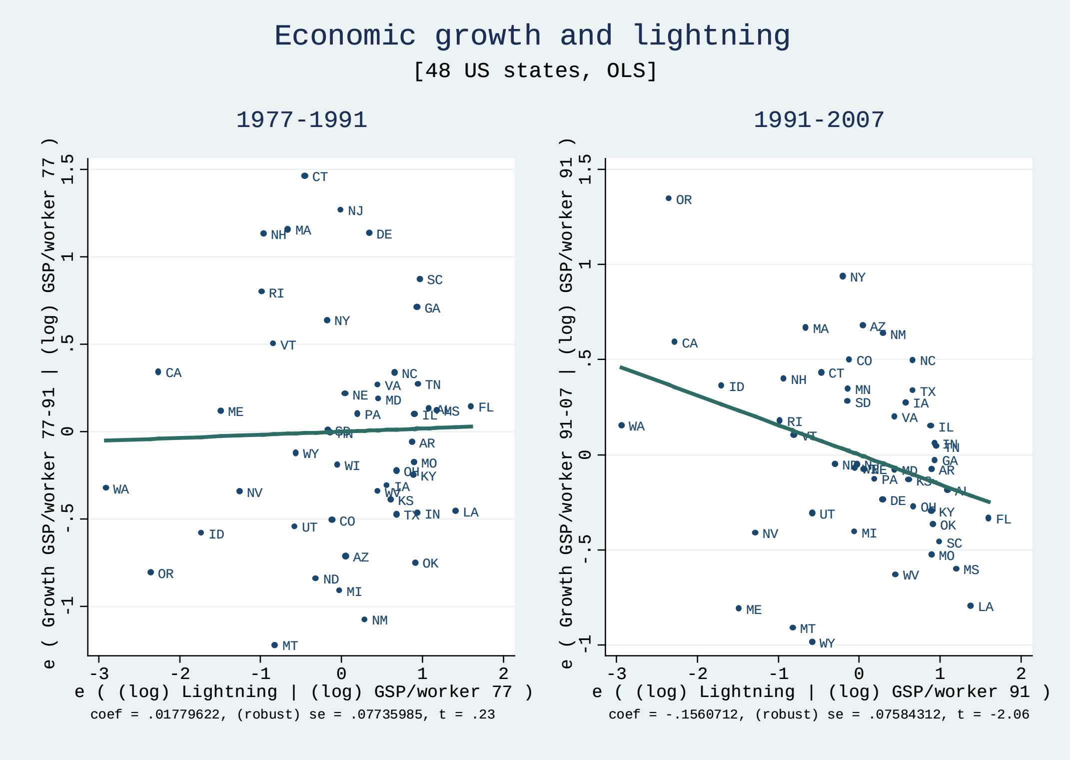
		Economy structure			Trade & Integration			Institutions			Religion	Race & ethnicity			Urbanization	Age structure	
ADDITIONAL CONTROL:		Share of agriculture in GSP, 1991	Share of government in GSP, 1991	Share of manufacturing in GSP, 1991	(log) FDI per capita, 1991	(log) Agricultural exports per capita, 1991	(log) Population, 1991	Soldier mortality, 1829-1854	% of workforce in mining, 1880	% of slavery, 1860	% population attending a church or a sinagogue almost every week, av. 2004-2006	% white population, 1990	% black population, 1990	% Hispanic origin population, 1990	% urban population, 1990	% population 15 years or less, 1990	% population 15-64 years, 1990
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Dependent variable:	**Panel A: % of households with a personal computer at home, 2003**																
(log) Lightning	-2.66***	-3.16***	-2.71***	-2.58***	-2.58***	-2.68***	-2.75***	-3.78***	-2.63***	-2.57***	-2.63***	-2.20**	-2.12**	-2.66***	-3.01***	-2.62***	-2.69***
	[0.80]	[0.92]	[0.84]	[0.84]	[0.79]	[0.82]	[0.80]	[0.80]	[0.77]	[0.86]	[0.84]	[0.89]	[0.91]	[0.83]	[0.83]	[0.87]	[0.86]
ADDITIONAL CONTROL:		-0.35	-0.046	0.13*	-1.07	-0.22	0.83	1.76**	0.03	-0.015	0.073	0.18**	-0.13	-0.036	0.063	0.10	0.10
		[0.27]	[0.20]	[0.075]	[1.35]	[0.51]	[0.52]	[0.65]	[0.060]	[0.054]	[0.27]	[0.074]	[0.082]	[0.090]	[0.052]	[0.39]	[0.44]
R-squared	0.84	0.85	0.84	0.85	0.84	0.84	0.85	0.86	0.84	0.84	0.84	0.86	0.85	0.84	0.85	0.84	0.84
Regional fixed effects (8 BEA economic regions)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
H_0: Regional FEs = 0 (p value)	0.02	0.04	0.04	0.02	0.02	0.02	0.01	0.001	0.04	0.03	0.11	0.02	0.01	0.10	0.03	0.02	0.03
Dependent variable:	**Panel B: % of households with Internet access at home, 2003**																
(log) Lightning	-1.69*	-1.15***	-1.07**	-1.19**	-1.08**	-0.99**	-1.18***	-1.17***	-1.27***	-1.27***	-1.34**	-0.85*	-0.83*	-1.21**	-1.12**	-0.98**	-0.99**
	[0.88]	[0.41]	[0.40]	[0.46]	[0.41]	[0.44]	[0.41]	[0.42]	[0.45]	[0.44]	[0.63]	[0.46]	[0.48]	[0.49]	[0.43]	[0.37]	[0.41]
ADDITIONAL CONTROL:		-0.14	-0.18	0.12	-1.46	-0.36	0.40	0.16	-0.05	0.025	0.15	0.21***	-0.11	-0.14*	-0.031	-0.49	0.41
		[0.19]	[0.23]	[0.084]	[1.64]	[0.37]	[0.39]	[0.53]	[0.043]	[0.050]	[0.29]	[0.060]	[0.080]	[0.070]	[0.039]	[0.34]	[0.33]
R-squared	0.82	0.77	0.78	0.78	0.78	0.78	0.77	0.77	0.78	0.77	0.77	0.83	0.78	0.80	0.77	0.79	0.78
Regional fixed effects (8 BEA economic regions)	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
H_0: Regional FEs = 0 (p value)	0.28	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Dependent variable:	**Panel C: IT investments of manufacturing firms, 2007**																
(log) Lightning	-1.69**	-1.66**	-1.98***	-1.69**	-1.77**	-1.71**	-1.64**	-1.36*	-1.63**	-1.32*	-1.87***	-1.53**	-1.24*	-1.67***	-1.72**	-1.79***	-1.69**
	[0.64]	[0.74]	[0.55]	[0.64]	[0.65]	[0.63]	[0.68]	[0.71]	[0.60]	[0.66]	[0.57]	[0.66]	[0.64]	[0.56]	[0.64]	[0.59]	[0.66]
ADDITIONAL CONTROL:		0.021	-0.28**	-0.011	1.06	-0.21	-0.37	-0.52	0.048*	-0.059***	-0.43***	0.06	-0.10**	0.094**	0.006	-0.27**	0.028
		[0.20]	[0.13]	[0.055]	[0.79]	[0.31]	[0.43]	[0.42]	[0.025]	[0.020]	[0.14]	[0.037]	[0.042]	[0.042]	[0.032]	[0.11]	[0.21]
R-squared	0.63	0.63	0.68	0.63	0.65	0.63	0.64	0.64	0.64	0.67	0.70	0.64	0.68	0.67	0.63	0.66	0.63
Regional fixed effects (8 BEA economic regions)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
H_0: Regional FEs = 0 (p value)	0.09	0.10	0.00	0.09	0.05	0.09	0.04	0.06	0.04	0.01	0.01	0.05	0.03	0.09	0.10	0.10	0.10

Notes. OLS estimates. All regressions have 48 observations, include a constant term, and control for the levels of (log) real Gross State Product per worker, enrollment rates, and % of population with a high school or higher degree in 1991, and the % of population with a BA degree in 1990. The dependent variables are (Panel A) the percentage of household with access to a personal computer at home in 2003, (Panel B) the % of households with access to Internet at home, and (Panel C) the level of IT investments in the manufacturing sector, measured as the amount capital expenditures on computers and peripheral data processing equipment, relative to all non-construction capital expenditures, respectively. Lightning is the average number of flashes per year per square km, measured by flash-detectors. Robust standard errors in brackets. Asterisks ***, **, and * indicate significance at the 1, 5, and 10%, respectively.

Table 12. Lightning, IT diffusion, and economic growth

Dependent variable:	Average annual growth in GSP per worker, 1991-2007														
	OLS													IV	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(log) Real GSP per worker, 1991	-0.66	-0.82*	-0.99**	-0.89**	-0.76*	-0.92**	-0.90**	-0.99**	-1.29***	-1.35***	-1.30***	-1.23***	-1.26***	-1.23**	-1.25***
	[0.41]	[0.44]	[0.45]	[0.35]	[0.42]	[0.43]	[0.35]	[0.43]	[0.42]	[0.46]	[0.44]	[0.44]	[0.36]	[0.54]	[0.33]
(log) Lightning	-0.16**				-0.093	-0.064	0.024	0.066	0.029	0.15					
	[0.076]				[0.10]	[0.092]	[0.057]	[0.081]	[0.086]	[0.15]					
Computer at home, 2003		0.028**			0.017			0.0063	0.021	0.051	0.029				
		[0.012]			[0.016]			[0.036]	[0.037]	[0.039]	[0.036]				
Access to Internet at home, 2003			0.033***			0.026*		0.0064	0.0019	-0.0095	0.0051				
			[0.011]			[0.014]		[0.036]	[0.036]	[0.038]	[0.037]				
Manufacturing firms' IT investments, 2007				0.16***			0.17***	0.17***	0.15***	0.15***	0.13***	0.13***	0.14***	0.13**	0.15**
				[0.025]			[0.027]	[0.029]	[0.034]	[0.038]	[0.034]	[0.033]	[0.031]	[0.064]	[0.062]
Observations	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
R-squared	0.15	0.15	0.19	0.57	0.17	0.20	0.57	0.58	0.62	0.71	0.70	0.67	0.60	.	.
Instrumented variable	.	.	.	.	.	.	.	.	.	.	.	.	.	Manufacturing firms' IT investments, 2007	
Instrument	.	.	.	.	.	.	.	.	.	.	.	.	.	(log) Lightning	
1st stage F statistic (Kleibergen-Paap Wald F stat)	.	.	.	.	.	.	.	.	.	.	.	.	.	6.96	14.38
Weak-instrument robust inference: Stock-Wright LM S statistic (p val)	.	.	.	.	.	.	.	.	.	.	.	.	.	0.061	0.067
Human capital controls (enrollment, high school or higher, BA)	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional fixed effects (8 BEA economic regions)	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	No	Yes	No
H_0: Regional FEs = 0 (p value)	.	.	.	.	.	.	.	.	.	0.24	0.24	0.32	.	0.12	.

Notes. OLS and IV estimates. The dependent variable in all regressions is the average annual growth rate in GSP per worker over the period 1991-2007. Columns 14 and 15 report 2SLS regressions, where manufacturing firms' IT investments are instrumented by (log) lightning density. Access to a computer and Internet at home are measured as the % of households by state. IT investments at manufacturing firms are measured as the % of capital expenditures on computers and data processing equipment, relative to all non-construction capital expenditures for all firms in the manufacturing sector. Lightning is the average number of flashes per year per square km, measured by flash-detectors. All regressions include a constant. Robust standard errors in brackets. ***, **, and * indicate significance at the 1, 5, and 10%, respectively.



Economic growth and lightning

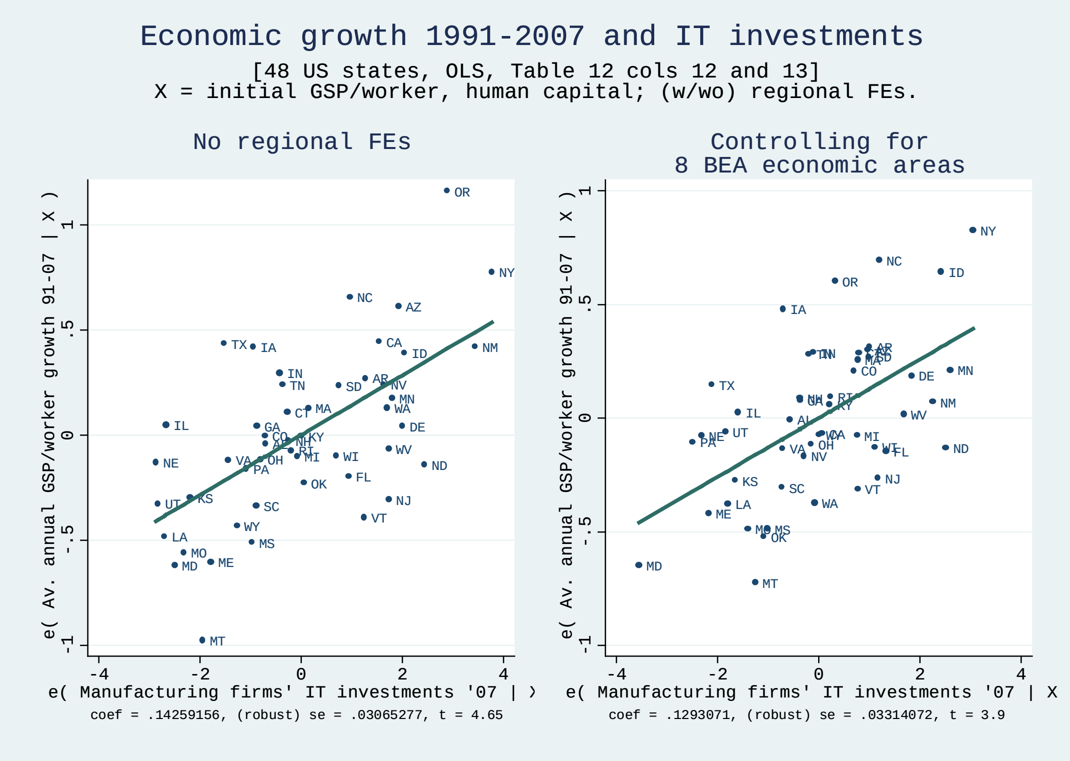
[48 US states, OLS]

1977-1991

1991-2007

coef = .01779622, (robust) se = .07735985, t = .23

coef = -.1560712, (robust) se = .07584312, t = -2.06



Economic growth 1991-2007 and IT investments

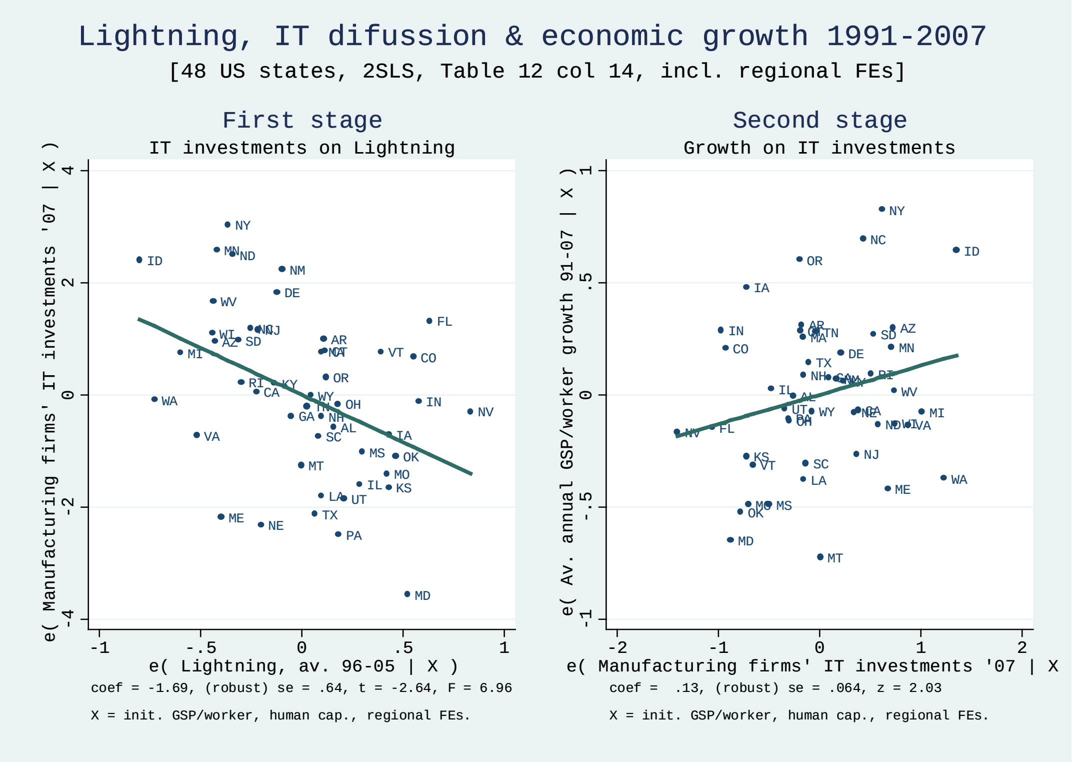
[48 US states, OLS, Table 12 cols 12 and 13]
X = initial GSP/worker, human capital; (w/wo) regional FEs.

No regional FEs

Controlling for
8 BEA economic areas

coef = .14259156, (robust) se = .03065277, t = 4.65

coef = .1293071, (robust) se = .03314072, t = 3.9



Lightning, IT difussion & economic growth 1991-2007

[48 US states, 2SLS, Table 12 col 14, incl. regional FEs]

First stage

IT investments on Lightning

coef = -1.69, (robust) se = .64, t = -2.64, F = 6.96

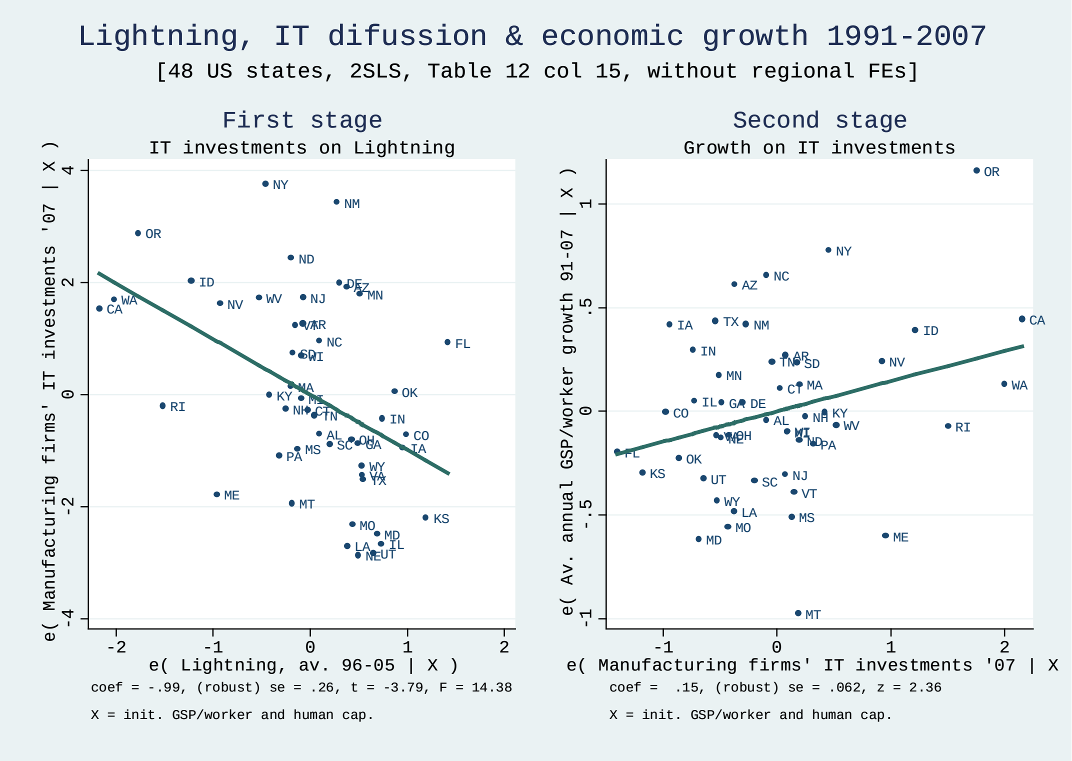
X = init. GSP/worker, human cap., regional FEs.

Second stage

Growth on IT investments

coef = .13, (robust) se = .064, z = 2.03

X = init. GSP/worker, human cap., regional FEs.



Lightning, IT difussion & economic growth 1991-2007

[48 US states, 2SLS, Table 12 col 15, without regional FEs]

First stage

IT investments on Lightning

coef = -.99, (robust) se = .26, t = -3.79, F = 14.38

X = init. GSP/worker and human cap.

Second stage

Growth on IT investments

coef = .15, (robust) se = .062, z = 2.36

X = init. GSP/worker and human cap.

Table A1. Tests for whether lightning is a constant plus white noise

	Breusch-Godfrey test			Runs test	
	test-statistic	p-value	N of lags*	test-statistic	p-value
Aggregate US	0.02	0.88	1	0.46	0.65
Alabama	0.61	0.43	1	-0.22	0.82
Arizona	0.16	0.69	1	-0.13	0.90
Arkansas	0.16	0.69	1	1.67	0.09
California	0.48	0.49	1	-0.12	0.91
Colorado	0.12	0.73	1	0.25	0.80
Florida	0.02	0.90	1	-0.70	0.49
Georgia	0.00	0.95	1	0.25	0.80
Idaho	0.02	0.90	1	0.72	0.47
Illinois	0.20	0.65	1	-1.64	0.10
Indiana	1.67	0.20	1	-0.22	0.82
Iowa	0.20	0.66	1	-0.22	0.82
Kansas	0.58	0.44	1	0.84	0.40
Kentucky	0.24	0.62	1	0.25	0.80
Louisiana	0.06	0.81	1	-0.70	0.49
Maine	1.05	0.31	1	0.25	0.80
Maryland	0.01	0.94	1	0.25	0.80
Massachusetts	1.29	0.26	1	0.72	0.47
Michigan	0.33	0.56	1	-0.70	0.49
Minnesota	0.00	0.98	1	-1.64	0.10
Mississippi	0.98	0.32	1	-2.12	0.03
Missouri	0.19	0.66	1	0.36	0.72
Montana	0.71	0.40	1	-2.12	0.03
Nebraska	0.22	0.64	1	-0.70	0.49
Nevada	0.02	0.88	1	0.72	0.47
New Mexico	1.25	0.26	1	-0.22	0.82
New York	7.52	0.02	2	0.36	0.72
North Carolina	0.74	0.39	1	-1.45	0.15
North Dakota	5.30	0.07	2	-0.22	0.82
Ohio	0.03	0.85	1	-0.70	0.49
Oklahoma	2.97	0.09	1	-1.64	0.10
Oregon	0.64	0.42	1	-1.45	0.15
Pennsylvania	5.25	0.07	2	0.72	0.47
South Carolina	0.23	0.63	1	-0.22	0.82
South Dakota	2.93	0.09	1	1.33	0.18
Tennessee	0.22	0.64	1	-0.22	0.82
Texas	3.79	0.05	1	-0.22	0.82
Utah	4.54	0.03	1	-0.70	0.49
Virginia	4.68	0.03	1	-0.22	0.82
Washington	0.48	0.49	1	-0.61	0.54
West Virginia	4.56	0.03	1	0.72	0.47
Wisconsin	0.57	0.45	1	-1.17	0.24
Wyoming	0.09	0.77	1	-0.22	0.82

Notes. The residuals are obtained from regressing lightning on a constant for each of the 42 states over the period 1977-1995. H_0: Residuals are not serially correlated. Lightning is average number of flashes per year per square km, measured at weather stations.

*: Number of lags selected by Schwarz's information criteria.

Table A2. Correlations: Lightning and US Bureau of Economic Analysis' 8 Economic Areas

Dependent variable:	Lightning		(log) Lightning	
	(1)	(2)	(3)	(4)
Far West	0.29***	(dropped)	-1.43***	(dropped)
	[0.10]	.	[0.32]	.
Great lakes	3.85***	3.56***	1.26***	2.69***
	[0.74]	[0.75]	[0.22]	[0.39]
Mid East	2.57***	2.29***	0.92***	2.35***
	[0.28]	[0.30]	[0.11]	[0.34]
New England	0.94***	0.65***	-0.11	1.32***
	[0.12]	[0.16]	[0.14]	[0.35]
Plains	2.99***	2.71***	1.00***	2.43***
	[0.54]	[0.55]	[0.18]	[0.37]
Rocky Mountain	1.15***	0.86***	0.021	1.45***
	[0.24]	[0.26]	[0.26]	[0.41]
Southeast	6.00***	5.71***	1.74***	3.17***
	[0.64]	[0.65]	[0.10]	[0.34]
Southwest	3.72***	3.43***	1.26***	2.69***
	[0.66]	[0.67]	[0.18]	[0.37]
Constant	.	0.29***	.	-1.43***
	.	[0.10]	.	[0.32]
Observations	48	48	48	48
R-squared	.	0.69	.	0.84

Notes: OLS regressions. Lightning is the average (1996-2005) number of flashes per year per square km, measured by flash-detectors. 8 economic areas defined by the US BEA. Robust standard errors in brackets. ***, **, and * indicate significance at the 1, 5, and 10%, respectively.

Table A3. Growth, lightning, and regional fixed effects (BEA economic areas) - controlling for human capital

Dependent variable:	Average annual growth in GSP per worker over periods of 10 years (1977 - 1987, 1987 - 1997, 1997 - 2007)							
BEA economic area:	Far West	Great Lakes	Mid East	New England	Plains	Rocky Mountain	Southeast	Southwest
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(log, initial) Real GSP per worker	-1.85***	-1.80***	-1.86***	-1.71***	-1.78***	-1.82***	-1.80***	-1.80***
	[0.41]	[0.43]	[0.44]	[0.42]	[0.43]	[0.41]	[0.41]	[0.41]
(log) Lightning × t_{77-87}	-0.098	-0.12	-0.12	-0.10	-0.13	-0.11	-0.12	-0.11
	[0.13]	[0.11]	[0.11]	[0.11]	[0.11]	[0.12]	[0.11]	[0.11]
(log) Lightning × t_{87-97}	-0.092	-0.12	-0.12	-0.098	-0.12	-0.11	-0.12	-0.11
	[0.099]	[0.083]	[0.083]	[0.084]	[0.084]	[0.085]	[0.085]	[0.085]
(log) Lightning × t_{97-07}	-0.18*	-0.21**	-0.21**	-0.19**	-0.21***	-0.21***	-0.22***	-0.21**
	[0.10]	[0.080]	[0.079]	[0.084]	[0.078]	[0.078]	[0.080]	[0.079]
BEA economic area	0.11	-0.0093	0.09	0.16	0.026	-0.33	0.054	-0.091
	[0.20]	[0.14]	[0.24]	[0.17]	[0.17]	[0.22]	[0.15]	[0.099]
Observations	144	144	144	144	144	144	144	144
R-squared	0.44	0.44	0.44	0.45	0.44	0.46	0.44	0.44
Human capital controls (enrollment, high school or higher, BA)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes. Pooled OLS estimates. The dependent variable is the yearly growth rate of GSP per worker over the periods 1977-1987, 1987-1997, and 1997-2007. Lightning is the average number of flashes per year per square km, measured by flash-detectors. The different proxies for human capital (enrollment rates, % of population with high school or higher, or BA degree) are described in the appendix, and measured at the beginning of each 10-year period (1977, 1987 and 1997), except for enrollment rates (measured in 1980 instead of 1977 for the first period) and the % of population with a highschool degree or higher (measured in 1980, 1990 and 2000 instead of 1977, 1987 and 1997 for each respective period), due to data availability. The set of region fixed effects accounts for the 8 US Bureau of Economic Analysis' economic areas. All regressions include a constant and a full set of time-dummies. Robust standard errors in brackets, adjusted for clustering at the state level. Asterisks ***, **, and * indicate significance at the 1, 5, and 10%, respectively.

Table A4. Correlations: Lightning and geographic/climate variables

Dependent variable:	(log) Lightning											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(log) Temperature (C degrees)	1.20***										0.091	0.056
	[0.17]										[0.36]	[0.39]
(log) Precipitation (cm/year)		0.084									-0.24	-0.22
		[0.49]									[0.30]	[0.27]
(log) Tornado intensity (av EF-scale)			0.088								0.78**	0.76**
			[0.33]								[0.32]	[0.28]
(log) Hail size (cm)				2.30*							1.68	1.54
				[1.24]							[1.16]	[0.99]
(log) Wind speed (km/h)					-0.077						0.046	0.036
					[0.31]						[0.20]	[0.17]
(log) Humidity (% moisture in air)						-0.32					-1.39	-1.37
						[1.25]					[1.49]	[1.42]
(log) Cloudiness (days/year)							-1.04**				0.68	0.88
							[0.47]				[1.13]	[0.73]
(log) Sunshine (days/year)								1.39***			-0.31	
								[0.49]			[0.98]	
(log) Elevation (m above sea level)									-0.20**		-0.097	-0.096
									[0.078]		[0.11]	[0.074]
(log) Latitude (degrees)										-4.30***	-5.40***	-5.47***
										[0.61]	[1.19]	[1.12]
Observations	48	48	48	48	48	48	48	47	48	48	47	48
R-squared	0.90	0.84	0.84	0.85	0.84	0.84	0.87	0.87	0.86	0.93	0.96	0.96
Regional fixed effects												
(8 BEA economic regions)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
H_0: Regional FEs = 0 (p value)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Notes. OLS regressions. All regressions include a constant and control for the 8 BEA economic regions (Far West excluded). Robust standard errors in brackets. Lightning is the average number of flashes per year per square km, measured by flash-detectors. Temperature, precipitation, tornado intensity, hail size and wind speed are averages over the period 1997-2007. Humidity, cloudiness and sunshine are state averages through 2007, as reported by the US National Oceanic and Atmospheric Administration (NOAA). Data sources and definitions for all variables are provided in the Data appendix. Data for all variables are available for the 48 contiguous US states, except sunshine, which has missing data for Delaware. ***, **, and * indicate significance at the 1, 5, and 10%, respectively.

Table A5. Correlations: Lightning, historical and trade variables

Dependent variable:	(log) Lightning												
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Controls for history:													
% of workforce in mining, 1880	-0.56												-0.52
	[1.36]												[1.32]
Average no. of cooling degree days		0.030*											0.025
		[0.017]											[0.018]
% of 1860 population in slavery			1.40***										0.52
			[0.36]										[1.43]
Access to navigable water				0.038									-0.17
				[0.30]									[0.26]
% of 1860 population on large slave plantations					1.76***								-0.035
					[0.53]								[1.84]
Settler origin: English						-0.28							0.012
						[0.18]							[0.18]
Settler origin: French							0.17						0.26
							[0.16]						[0.17]
Settler origin: Spanish								0.24					-0.027
								[0.21]					[0.19]
Settler origin: Dutch									-0.14				-0.17
									[0.18]				[0.26]
Average annual soldier mortality in 1829-1838, 1839-1854, %										29.2***			20.3**
										[5.17]			[9.19]
Controls for trade:													
(log) Agricultural exports per capita											-0.11		-0.14
											[0.097]		[0.093]
(log) FDI per capita												0.27*	0.083
												[0.16]	[0.16]
Observations	48	48	48	48	48	48	48	48	48	48	48	48	48
R-squared	0.84	0.87	0.86	0.84	0.85	0.85	0.85	0.85	0.84	0.88	0.85	0.85	0.91
Regional fixed effects (8 BEA economic regions)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
H_0: Regional FEs = 0 (p value)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Notes. OLS regressions. All regressions include a constant and control for the 8 BEA economic regions (Far West excluded). Robust standard errors in brackets. Lightning is the average number of flashes per year per square km, measured by flash-detectors. Historical variables taken from Mitchener and McLean (2004). Agricultural exports and FDI per capita are averages taken over the periods 1997-2007. Sources and definitions are provided in the Data appendix. ***, **, and * indicate significance at the 1, 5, and 10%, respectively.

Table A6. Correlations: Lightning, initial GSP per worker, and human capital

Dependent variable:	(log) Lightning				
	(1)	(2)	(3)	(4)	(5)
(log) Real GSP per worker, 1991	1.06**				1.11**
	[0.45]				[0.53]
Enrollment rate, 1991		-0.025			-0.019
		[0.030]			[0.028]
High school degree or higher, 1990			-0.0089		-0.014
			[0.026]		[0.030]
Bachelor's degree or higher, 1991				0.0096	-0.0032
				[0.030]	[0.036]
Observations	48	48	48	48	48
R-squared	0.86	0.85	0.84	0.84	0.86
Regional fixed effects					
(8 BEA economic regions)	Yes	Yes	Yes	Yes	Yes
H_0: Regional FEs = 0 (p value)	0.00	0.00	0.00	0.00	0.00

Notes. OLS regressions. All regressions include a constant and control for the 8 BEA economic regions (Far West excluded). Robust standard errors in brackets. Lightning is the average number of flashes per year per square km, measured by flash-detectors. Sources and definitions for the human capital variables are provided in the Data appendix. ***, **, and * indicate significance at the 1, 5, and 10%, respectively.

Table A7. Correlations: Lightning and Caselli and Coleman's (2001) additional detereminants of IT diffusion

Dependent variable:	(log) Lightning																
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Share of agriculture in GSP, 1991	-0.11***																-0.17*
	[0.035]																[0.087]
Share of government in GSP, 1991		-0.058**															-0.039
		[0.026]															[0.034]
Share of manufacturing in GSP, 1991			-0.0058														-0.025
			[0.017]														[0.016]
(log) FDI per capita, 1991				0.20													-0.18
				[0.14]													[0.21]
(log) Agricultural exports per capita, 1991					-0.068												0.16
					[0.11]												[0.11]
(log) Population, 1991						0.078											-0.21
						[0.084]											[0.13]
Soldier mortality, 1829-1854							0.29***										0.19
							[0.052]										[0.12]
% of workforce in mining, 1880								-0.0056									-0.002
								[0.014]									[0.012]
% of slavery, 1860									0.014***								0.0026
									[0.0036]								[0.012]
% population attending a church or a sinagogue almost every week, av. 2004-2006										-2.21							1.01
										[4.49]							[4.22]
% white population, 1990											-1.79**						1.00
											[0.67]						[4.55]
% black population, 1990												2.76***					2.69
												[0.78]					[6.13]
% Hispanic origin population, 1990													0.66				0.50
													[1.28]				[2.33]
% urban population, 1990														1.27**			0.41
														[0.48]			[0.66]
% population 15 years or less, 1990															-4.03		-9.93*
															[4.73]		[5.50]
% population 15-64 years, 1990																4.71	-4.27
																[5.02]	[4.85]
Observations	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
R-squared	0.87	0.86	0.84	0.85	0.85	0.85	0.88	0.84	0.86	0.84	0.86	0.87	0.84	0.87	0.85	0.85	0.94
Regional fixed effects																	
(8 BEA economic regions)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
H_0: Regional FEs = 0 (p value)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Notes. OLS regressions. All regressions include a constant and control for the 8 BEA economic regions (Far West excluded). Robust standard errors in brackets. Lightning is the average number of flashes per year per square km, measured by flash-detectors. The set of additional determinants of IT diffusion is chosen following the relevant group of variables in Caselli and Coleman (2001). Sources and definitions for all the data are provided in the Data appendix. ***, **, and * indicate significance at the 1, 5, and 10%, respectively.