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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

There is compelling evidence to suggest that climate and geography profoundly affected the historical growth record (Diamond, 1997; Olsson and Hibbs, 2005; Putterman, 2008; Ashraf 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 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-

[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).

by-state basis, however, the process of IT diffusion, measured by per capita computers and Internet users, 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 well 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, 2006). Theoretically, it is therefore very plausible that lightning may importantly have increased IT user costs.[3] Naturally, 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

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

[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.

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 computers and Internet across the US. We find that the diffusion of computers and the Internet 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*.

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

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

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.

>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

[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.

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, 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 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, that lightning's correlation with growth is not due to other climate variables like high winds, rainfall and so on.

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, we estimate an equation of the following kind:

$$\log\left(\frac{y_{it}}{y_{it-10}}\right) = b_0 + b_1 \log\left(y_{it-10}\right) + b_2 \log\left(\text{lightning}_i\right) + \varepsilon_{it},$$

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

[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.

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 equation:

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

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.[9] 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. However, in the next section we do find that one particular growth determinant renders lightning insignificant: IT penetration.

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

The impact from lightning is economically significant as well. Consider the results pertaining to the “intermediate case”, which involves 10 year epochs. Taken at face value, the point estimate for the 1990s imply that a one 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 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.[10] Needless to say, this is a substantial effect.

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

3. Hypotheses and Explanations

3.1. 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.

Theory: The simple analytics of 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*. In what follows we develop a simple model that links the flash density (our independent variable in the regressions above) to IT capital accumulation, and thus IT diffusion and growth in output.

[10] 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.

Consider a representative firm producing output, Y, with the technology F(C). C is the stock of IT capital, whereas F(•) is a neoclassical production function, featuring positive and diminishing returns; for simplicity we ignore other inputs in production. The price of output is normalized to one and markets are competitive.

We assume the capital stock cannot be adjusted to its optimal level instantaneously. A reason would be the presence of (convex) installation costs. For simplicity, we ignore adjustment costs in the formal analysis, and assume instead that the IT capital stock simply follows an *ad hoc* adjustment rule capturing whatever frictions that prevent firms from adjusting the capital stock fully.[11]

Specifically, assuming time is continuous, the adjustment rule is $\dot{C} = \lambda \cdot (C^* - C)$, where $\dot{C}(= dC/dt)$ is the instantaneous change in the capital stock, λ is a positive parameter, C* is the optimal IT capital stock (to be determined below), and C is the current (or initial) stock of IT capital.[12] Hence, in each period the capital stock is mechanically adjusted towards its optimal level.

In the absence of convex adjustment costs, the optimal IT capital stock, C*, is given by the first order condition from the static profit maximization problem:

$$F'(C^*) = u,$$

where u is the user cost of capital. Ignoring taxes, the user cost formula is (Hall and Jorgenson, 1967):

$$u = p(r + \delta - \pi),$$

where p is the relative investment price, r is the real rate of return, δ is the depreciation rate of IT capital, and π is the instantaneous rate of change in the relative investment price.

Next, we assume the depreciation rate is increasing in the number of lightning strikes, n, in the surrounding area of the power conductor. That is,

[11] Nothing much is lost by this simplification. The key result obtained below, that the flash density reduces growth, can also be derived invoking convex costs of adjustment, at the costs of more algebra. In the interest of brevity, however, we stick with the simpler model.
[12] In the interest of brevity time indices have been suppressed.

$$\delta = \delta(n),\ \delta'(n) > 0.$$

The basic idea is that lightning strikes lead to power disturbances, which reduce the longevity of IT capital. This assumption has a sound physical foundation as observed in the Introduction. 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 be corrupted which causes damage to the equipment, 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). In reduced form then, more lightning strikes to the power supply implies higher IT capital depreciation.[13] We capture the physical links between lightning strikes and equipment damage by assuming $\delta'(n) > 0$.

[13] 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.

Finally, the number of strikes, n, per year (per 100 km line length) can be determined as (Chisholm, 2000)

$$n = 3.8 \cdot f \cdot h^{0.45},$$

where f is the *flash density* and h is the height (in meters) of the conductor above ground. This completes the model.

To see how the flash density impacts on IT diffusion, substitute n into the user cost expression, and invoke the first order condition from profit maximization. Then the optimal IT capital stock, C*, is given by

$$C^* = \Phi\left\{p\left[r + \delta\left(3.8 \cdot f \cdot h^{0.45}\right) - \pi\right]\right\},$$

where $\Phi \equiv F'^{-1}$. As a consequence, using the adjustment rule, the growth rate of the IT capital stock becomes

$$\frac{\dot{C}}{C} = \lambda \cdot \frac{\Phi\left\{p\left[r + \delta\left(3.8 \cdot f \cdot h^{0.45}\right) - \pi\right]\right\}}{C} - \lambda.$$

This expression forms the basis for the following observation:

Proposition: *Conditional on the initial capital stock, a higher flash density leads to a lower growth rate of the IT capital stock*.

Proof: Since $\Phi' < 0$, $\delta' > 0$ and $\lambda > 0$, the result follows immediately from differentiation. QED

Hence, 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 intuition is that a higher flash density rate increases the frequency of power disturbances, IT capital depreciation, the user cost of IT capital, and thus lowers IT investments. Moreover, as output is increasing in the IT capital stock, Y=F(C), growth in output will similarly tend to be slower in areas with greater lightning activity, conditional on the initial level of output.[14]

[14] It should be clear that the advocated mechanism is robust in a general equilibrium setting. Through elevated capital depreciation, higher lightning density would work to reduce the long-run (steady state) level of capital per worker in any neoclassical growth model. Hence, conditional on the initial capital stock, growth will be reduced in transition by an increasing flash density.

It is worth reiterating that firms may take pre-emptive actions so as to reduce the impact of lightning on the cost of capital; this could 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; in terms of the model above, it amounts to an increasing investment price, *p*. Hence, even if we take the likely "pre-emptive measures" into account, more lightning prone areas will tend to feature slower growth in IT capital, and thus slower output growth.

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.[15] Hence, it seems plausible that this mechanism also could affect comparative IT penetration across US States.

These 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 the World Wide Web); a conceivable reason why firms chose to intensify IT investments during the same period.[16] 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,

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

[16] 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/ .

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).[17]

In sum, these factors would all contribute to increasing the importance of the flash density to IT investments, and thus to growth, during the 1990s. But the question is whether empirically this theory can account for the apparent increasing macroeconomic sensitivity to lightning.

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 two measures. Both measures derive from a supplement to the 2003 Current Population Survey, which contained questions about computer and Internet use. The first measure is percentage of households with access to Internet, and the second measure is percentage of households with a PC. A few remarks on these data are necessary.

First, using household data on computer and Internet penetration is admittedly not optimal. Rather, we would have preferred to employ data on IT investments by firms. Unfortunately, the Bureau of Economic Analysis does not produce state level data on IT capital. Nevertheless, it seems reasonable to expect a close link between individuals' use of IT on the job, and the propensity to adopt the same technology at home. As a result, the household data can be seen as a proxy for IT penetration at the firm level. Naturally, using a proxy variable induces

[17] 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.

measurement error. However, as the measurement error (in this case) is found in the dependent variable, it will only inflate the standard deviations of the estimated parameters thus making it less likely to find a statistically significant correlation with lightning activity.[18]

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 over-all investments, as in the simple model above. 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 at the household level, 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 thus lower IT intensity and thereby long-run productivity. Moreover, if the IT variable is grossly mismeasured, 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.

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

Finally, one may question whether there is value in using both 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

[18] We did consider *inferring* IT capital intensity at the state level since the Bureau of Economic Analysis does produce 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.

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 with the simple correlation between the flash density and the two IT measures for the 48 states in our sample. Figures 7 and 8 depict them.

>Figures 7 and 8 about here<

Visually, the strong negative correlations between the flash density and PC and Internet users, respectively, are immediately obvious. By 2003, states that experience lightning strikes at a higher frequency also have relatively fewer users of computers and the Internet.

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 the same type of information. Of course, in US cross-state data one expects differences in institutional quality to be orders of magnitude 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. [19]

>Tables 4A and 5A about here<

In Table 4A we report baseline results for Internet users; Table 5A contains similar regressions for personal computers. Since PCs emerged in the 1980s we measure the determinants of PC diffusion around 1980 whenever feasible. By contrast, since the WWW emerged in 1990, we measure the same initial conditions around 1990.

In column 1 of Table 4A we examine the simple correlation between Internet users and the flash density; the latter is highly significant and can account for nearly 40% of the variation in Internet users as of 2003. In the next 6 columns we include GSP per worker in 1991 along with various human capital measures. As is clear, most of the human capital variables are highly significant, along side GSP per worker and the flash density. This is consistent with previous findings (e.g., Caselli and Coleman, 2001; Beaudry et al., 2006). Still, the best fit is obtained when we employ the fraction of state population with a high school diploma or more (column 4); along with the flash density and (log) GSP per worker the three variables can account for three quarters of the variation in Internet users.

In an effort to check for robustness, Table 4B introduce additional controls (on top of human capital, income and lightning), one by one. Nowhere is the influence from the flash density

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

eliminated. Rather, the point estimate appears reasonably robust to the inclusion of alternative IT diffusion controls, economically as well as statistically.

>Tables 4B and 5B about here<

Next consider Table 5A. Column 1 confirms that lightning is strongly correlated with personal computer users; the R^2 is in fact slightly higher than what is true for Internet users. In general, the results for personal computers are rather similar to those involving Internet diffusion. Nevertheless, there are two differences worth a remark.

First, it appears that the measure of human capital that holds the strongest explanatory power vis-à-vis computers is the fraction of the state population with a bachelor degree or above (BA), rather than the high school variable. The difference in R^2 in the two specifications is marginal though (cf. columns 4 and 5). To ease comparability we have therefore chosen to stick with the high school measure in the context of the robustness checks. But the results are very similar if we used the BA variable instead. Second, initial GSP per worker is not significant in the regressions. Nevertheless, on theoretical grounds we have chosen to keep it in the regressions to follow.

Examining Table 5B it is clear that lightning is robust to the inclusion of plausible alternative determinants of diffusion. Again the point estimate for the flash density is very stable. Interestingly, comparing Tables 4 and 5, one may observe that the size of the coefficient assigned to the flash density is numerically very similar in the two separate specifications. This could be taken to suggest that it is the same basic mechanism that affects both computer and Internet diffusion, in keeping with the theory developed above.

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. However, there is a particular issue which may render the results of the analysis above misleading: clustering.

Lightning density is characterized by a degree of geographical clustering for which reason we need to worry about cluster fixed effects. If cluster fixed effects are uncorrelated with the independent variables, OLS remains consistent but will underestimate the variances of regression parameters. If, on the other hand, cluster fixed effects are correlated with the independent variables, OLS turns inconsistent as well (Cameron and Trivedi, 2005). The appropriate remedy depends on the structure of the clusters. With small clusters (i.e., many clusters and few observations within each cluster), the response is fairly straightforward. We can simply obtain cluster robust standard errors on account of independence across clusters.

However, with only 48 states, we face a problem of large clusters (i.e., few clusters and many observations within each cluster), for which reason the OLS cluster robust variance matrix is not a feasible option (Cameron and Trivedi, 2005; Angrist and Pischke, 2009). What we can do instead is to introduce cluster fixed effects via the cluster dummy variables model, as outlined in Cameron and Trivedi (2005). Introducing cluster fixed effects in this way serves to remove the intraclass error correlation that is responsible for both the potential inconsistency in the slope estimates and the bias in the variance matrix in the first place. In order to implement the cluster dummy variables model, we need to decide on the appropriate clusters. Since no "natural" cluster partition comes to mind, we employ two alternative partitions.

The first partition is based on a decomposition of the US power grid. The US has no "national power grid". Instead, the contiguous US states are divided into two main grids, the Eastern Interconnected System and the Western Interconnected System, and a minor grid, namely the Texas Interconnected System. Electric utilities in an interconnection are electrically tied together during normal system conditions and work at a synchronized frequency operating at an average of 60Hz. The Eastern and Western Interconnects have only very limited interconnections with each other, while a few states, including Texas, are linked to both. By construction, this partition ensures cluster independence across the main two grids; i.e., climatic influences on the Western Interconnect will not influence the Eastern Interconnect, and vice versa. Thus, power disturbances are independent across the two main interconnections but dependent within interconnections.

The second partition is simply based on the four US Census Bureau regions, namely Midwest, Northeast, South, and West. Visually, this partition corresponds well with the spatial distribution of lightning (see Figure 3).[20]

>Tables 6 and 7 about here<

Tables 6 and 7 report results from regressions where cluster dummy variables are included. In both tables, column 1 is without dummies, whereas columns 2 and 3 have Census regions and interconnection based dummies, respectively. In both tables, lightning retains significance regardless of the inclusion of cluster dummy variables. However, while the Census based clusters are jointly significant in both tables, the interconnection dummies are only significant in Table 7; i.e., when computer use is the dependent variable. It is also interesting to note that standard errors are always larger when cluster dummies are added. This is consistent with OLS underestimating the variances of regression parameters in the presence of cluster dependencies. The point estimates, however, are not statistically different across the columns of each respective table. Consequently, omission of the cluster dummies does not appear to induce an omitted variables bias. In sum, taking cluster issues into account does not impact on our results.

In spite of these checks 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 lightning is clearly robust to a reasonable set of alternative IT determinants, and it is robust to cluster fixed effects. Moreover, the point estimate seems stable across specifications. It falls in a fairly confined interval no matter which determinant we include on top of human capital and labor productivity. These characteristics provide a sound basis for

[20] We did not pursue the issue of cluster fixed effects in Section 2.2 since it is difficult to see how a cluster fixed effect can account for the *time varying* partial correlation between growth and lightning. Nevertheless, for completeness, we have run the regressions from Table 3 while including the cluster fixed effects as discussed above. For the case of 10 year epochs, results are basically identical to those reported above. The same goes for 5 and 15 year epochs when we rely on interconnection dummies. When we use Census regions and 5 and 15 year epochs, parameters are roughly unchanged but we lose a bit in terms of precision. However, we do obtain significance at the 12 percent level. Overall, there does not seem to be an omitted variables problem on account of cluster effects.

believing the estimates above can be taken to imply that lightning is causally impacting on the speed of IT diffusion.

If we take the parameter estimate for lightning seriously, what is the economic strength of the link? Using the estimate from column 4 in Table 4A we find that a one standard deviation increase in lightning leads to a reduction in Internet users by about 1 percent.[21] 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 a one standard deviation change in lightning can account for about 7% of the 95/5 gap; four standard deviations therefore motivates about 25% of the difference.

The final issue is whether IT can account for the link between growth and lightning. Table 8 shows the relevant regression results. We focus specifically on the 1991-2007 period, as this is the period during which lightning is significantly correlated with growth.

>Table 8 about here<

In column 1 of Table 8 the lightning-growth correlation is reproduced. In the following two columns we add the two IT measures. Individually, both are significantly and positively correlated with growth as expected. The interpretation of the two right hand side 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 PCs, which started diffusing far earlier. If the IT investment rate is the relevant control, the PC 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 PCs in Table 8.

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

The key result of the exercise is reported in columns 4-6. When the IT variables are added to the equation the flash density looses significance. The loss of significance is mainly attributable to a lower point estimate, which essentially is cut in half. A reasonable interpretation is that lightning appears in the growth regression due to its impact on IT diffusion. Column 6 introduces all three variables at once. Despite the obvious multicollinearity in this experiment (which explains the somewhat wobbly behavior of the Internet slope estimates), Internet remains significant. This means that the Internet dominates lightning (and computers) as a predictor of cross state growth rates in the Internet era: 1991 onwards.

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.

3.2 Climate Shocks

While the IT diffusion hypothesis is a viable explanation for the lightning-growth correlation, it is not *a priori* the only plausible one. 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). [22] 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.

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.[23]

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 9 and 10 report the answers. 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.

[22] 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.

[23] 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 9 and 10 about here<

Columns 2-11 of Table 9 examine the potentially time varying impact from each weather variable; column 1 reproduces the lightning regularity from Section 2.2. It is plain to see that none of the weather variables exhibit a similar growth correlation as that involving lightning. In fact, it is always the case that the variable in question is either insignificant, or tends to become less correlated with growth over time.

In Columns 2-11 of Table 10 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.

3.3 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).[24]

As in Section 3.2 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 11 and 12 about here<

In Table 11 we examine the impact from various historical determinants of productivity one-by-one. Interestingly, in several cases the impact does seem to vary across decades. Of particular note is column 11, which involves soldier mortality rates. Much like lightning the partial correlation seems stronger at the end of the period, compared to the beginning of the 1977-2007 period.

Table 12 includes both lightning and the individual controls. Since the soldier mortality rates 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 11 is of central importance. When both variables enter the growth regression only lightning retains explanatory power. The point estimate for the last period does decline a bit, and the statistical significance of lightning is somewhat reduced. But soldier mortality rates do 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.

[24] See the Data Appendix for details.

>Table 13 about here<

Finally, Table 13 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.

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. 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 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.[25] 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.

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. 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	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/.

[25] 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.

in 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 population of Hispanic origin	Data for race and Hispanic origin for the US, regions, divisions, and states (100-Percent Data). Source: US Census Bureau. 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

Figures

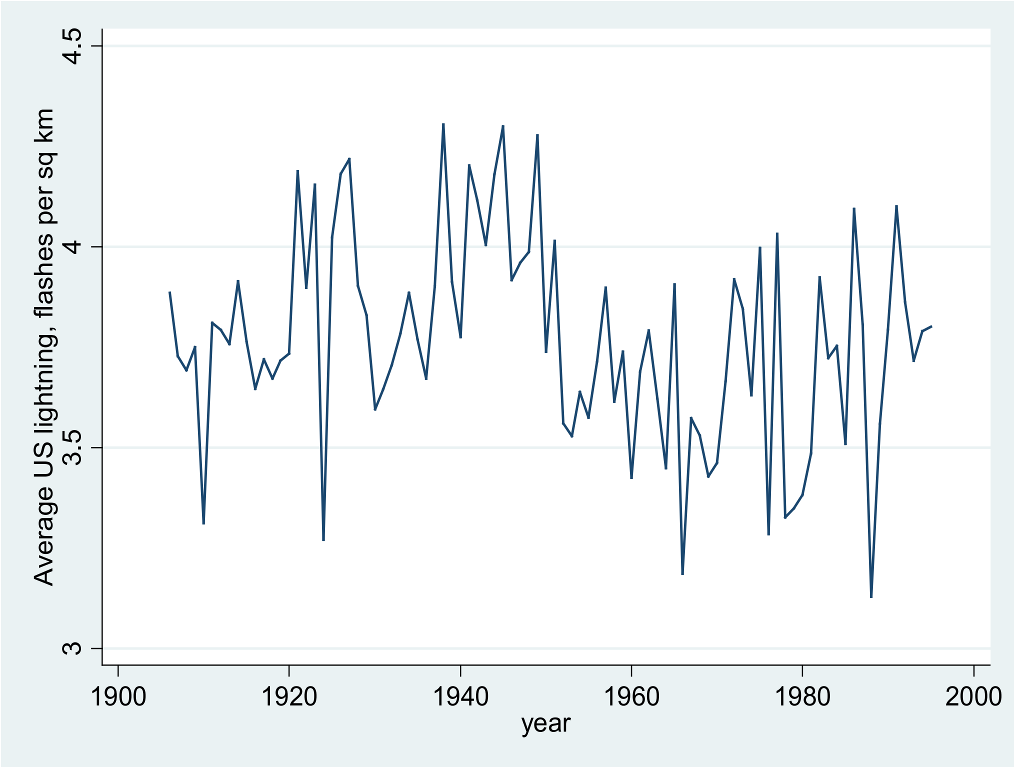

Figure 1. The average flash density in the US: 40 states
Source: Lightning observations from weather stations, transformed from thunder days (TD) into flash density (FD) using the formula FD = $0.04*TD^{1.25}$. See Data Appendix for details.
Notes: Only 40 states have complete information for the period 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.

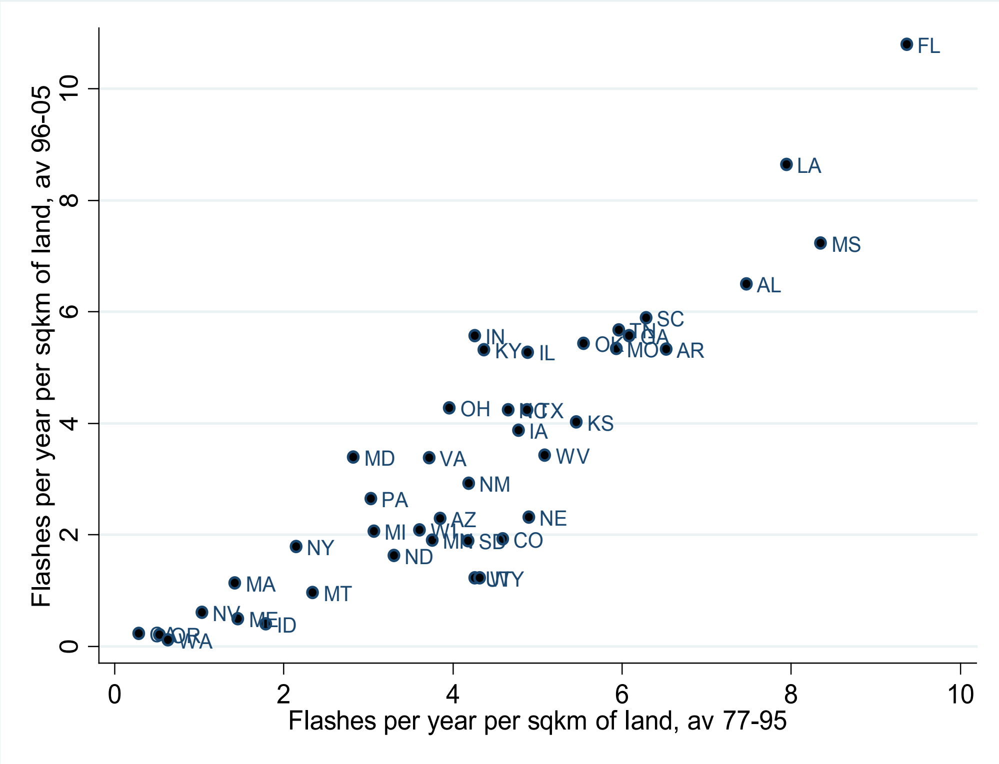

Figure 2. The average flash density 1977-95 versus 1996-2005: 42 states.

Sources: 1977-95 based on Thunder days (TD) from weather station observations, converted into flash density (FD) using the formula FD = $0.04 \cdot TD^{1.25}$. 1996-2005 data are based on ground detectors. See Appendix for further details.

Notes: The correlation is 0.90, and a regression, $FL_{96\text{-}05} = a + bFL_{77\text{-}95}$ returns: a=-0.99, b=1.05, R^2=0.81.

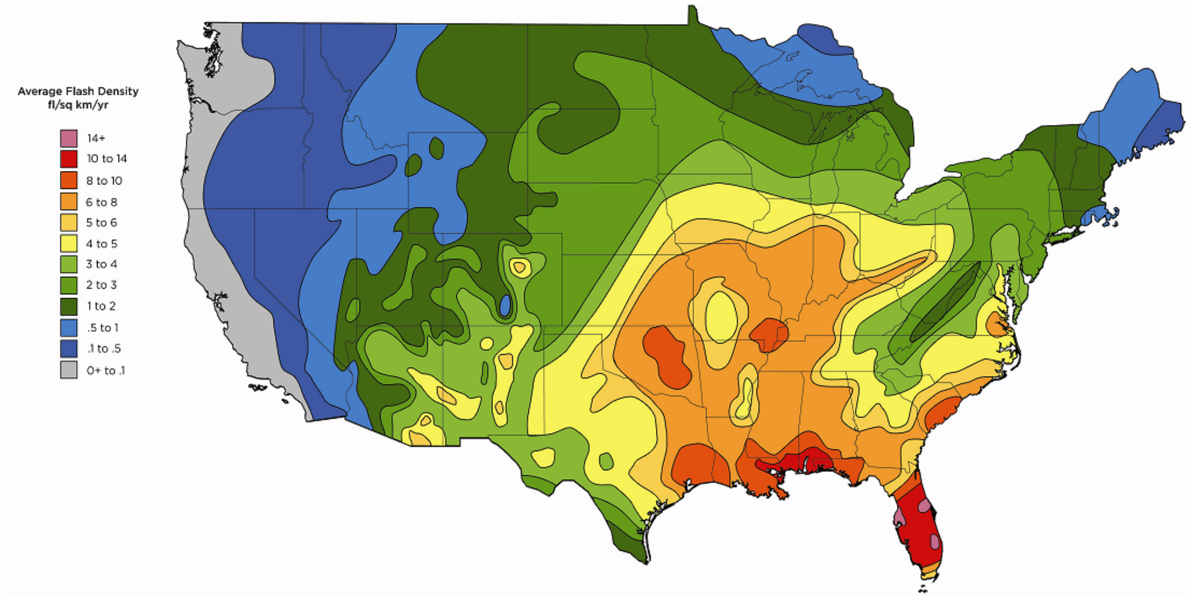

Figure 3. The distribution of flash densities across the US: 1996-2007.
Source: http://www.vaisala.com

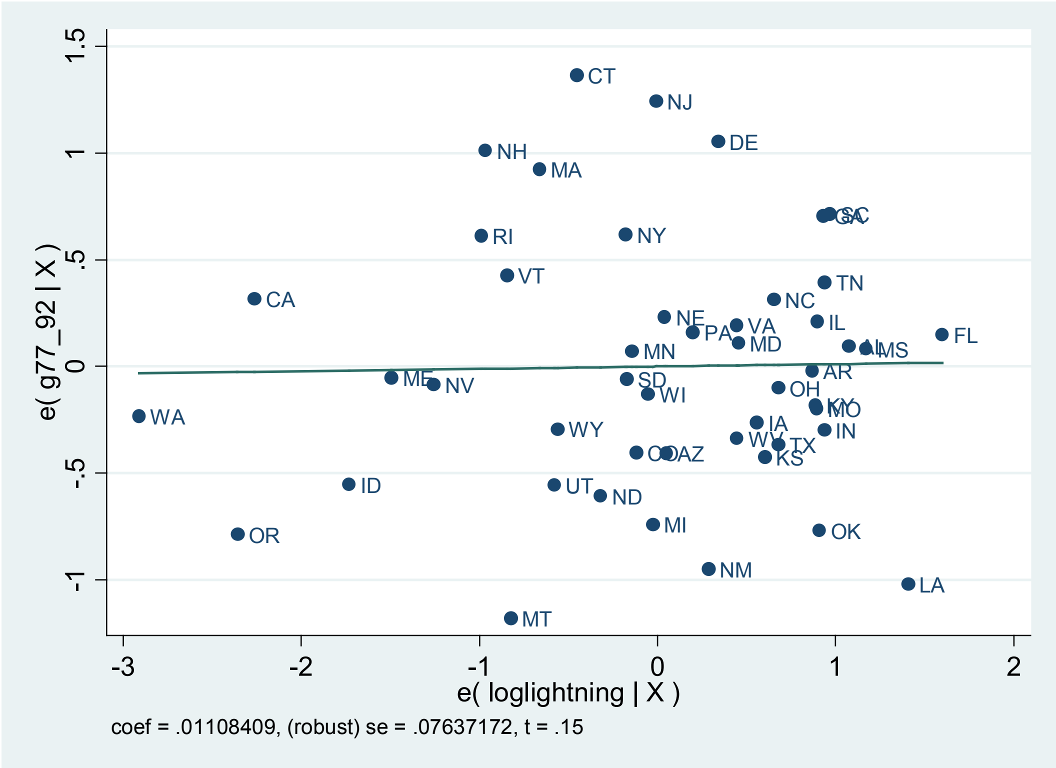

Figure 4. The correlation between state growth and (log) flash density, conditional on a constant and initial income per worker: 1977-1992.

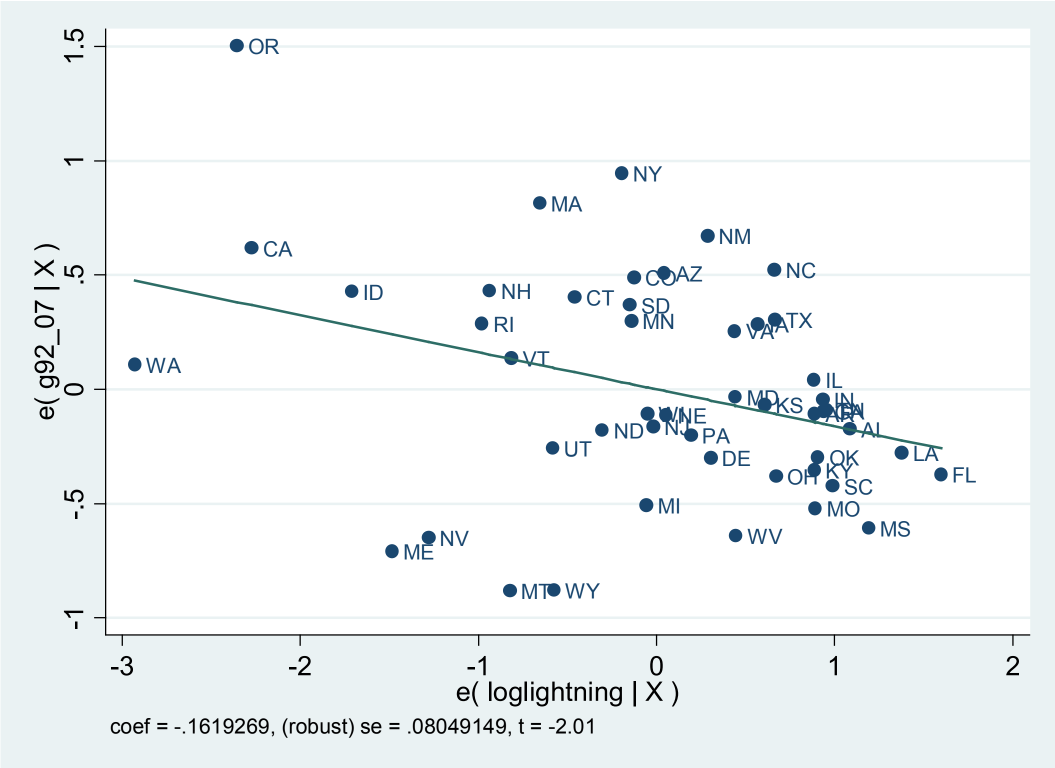

Figure 5. The correlation between state growth and (log) flash density, conditional on a constant and initial income per worker: 1992-2007.

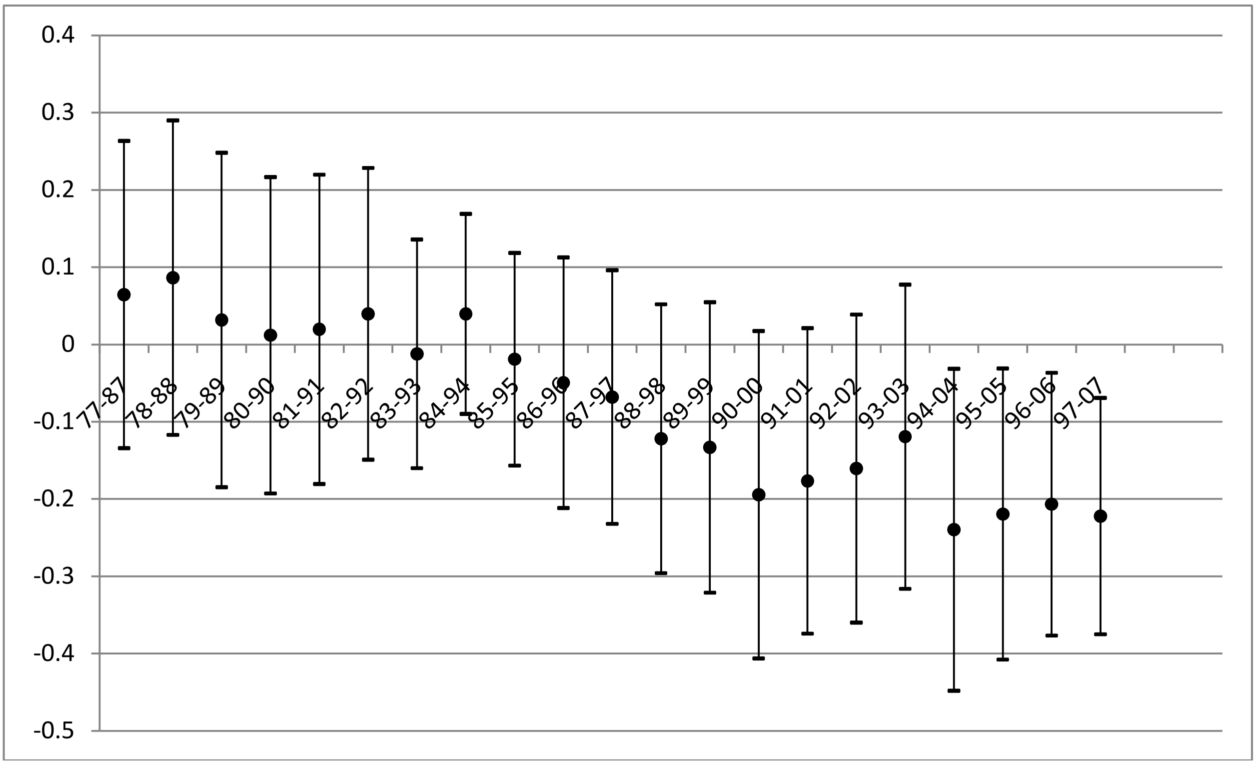

Figure 6. The lightning-growth nexus: 1977-2007.

Notes: The figure shows estimates for b_2 (and the associated 95 percent confidence interval) from regressions of the form: $\log(y_t)-\log(y_{t-10}) = b_0 + b_1\log(y_{t-10}) + b_2\log(\text{lightning})+e$, where y is gross state product per worker and t=1987,...,2007. 48 states; estimated by OLS.

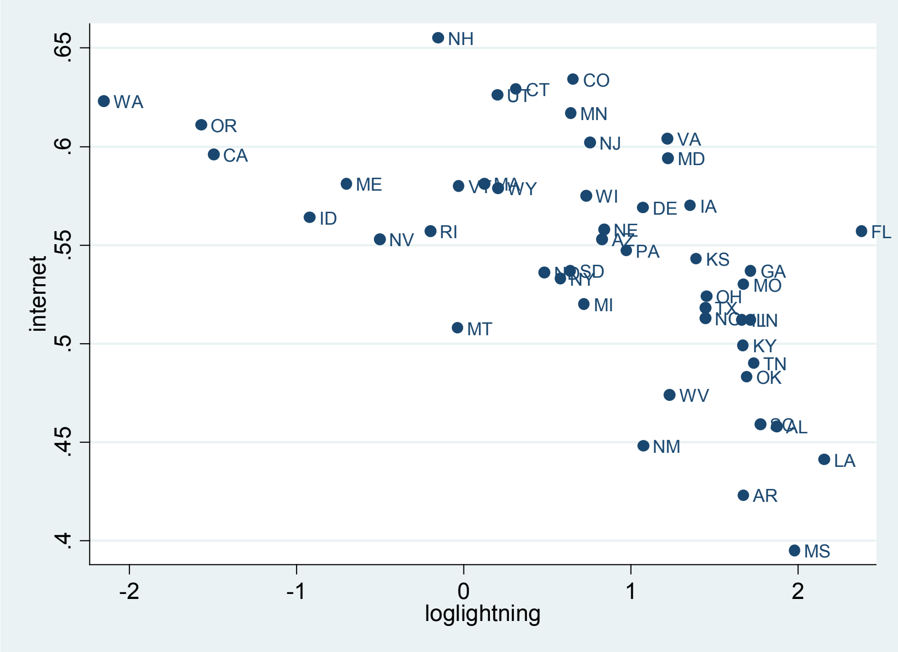

Figure 7. Lightning versus Internet users per 100 households in 2003.
Sources: See Data Appendix
Notes: The raw correlation between the two series is -0.62.

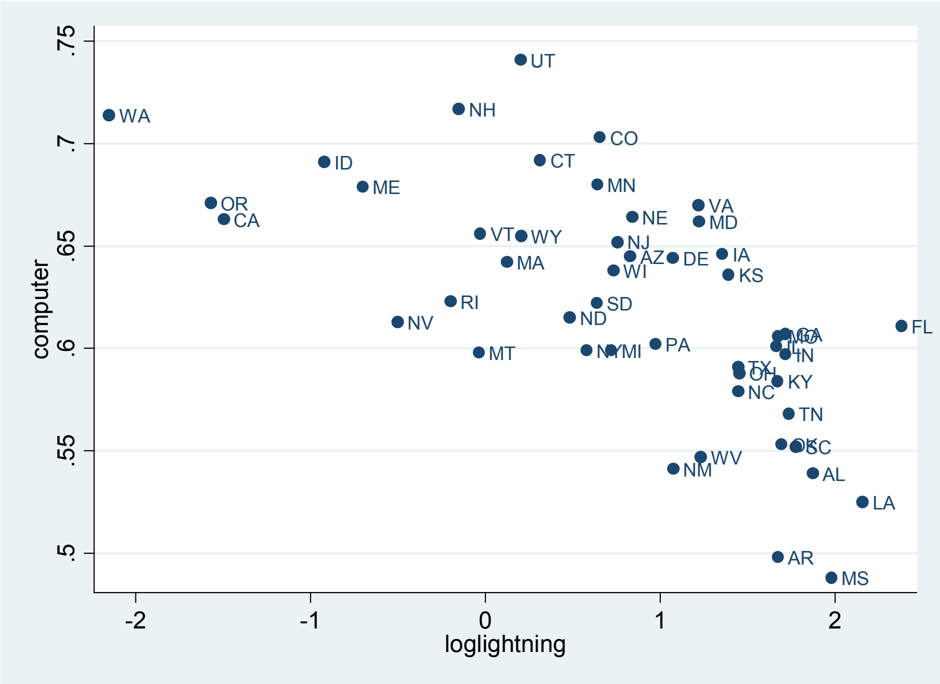

Figure 8. Lightning versus personal computers per 100 households in 2003.

Sources: See Data Appendix.

Notes: The raw correlation between the two series is -0.65.

Table 1. Dickey-Fuller test 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

	Obs.	Mean	Std. Dev.	Percentiles				
				99%	**75%**	**50%**	**25%**	**1%**
Lightning, average 1996-2005 (flashes/year/sq km)	48	3.18	2.39	10.79	5.30	2.48	1.23	0.12
Annual growth rate of real GSP per worker, average 1977-2007 (%)	48	1.07	0.42	1.97	1.37	1.07	0.82	0.10
Internet presence, 2003 (%)	48	54.4	5.9	65.5	58.1	55.0	51.2	39.5
Computer presence, 2003 (%)	48	62.1	5.7	74.1	66.3	61.9	59.0	48.8

Notes. Lightning defined as average number of flashes per year per square km over the period 1995-2006, measured by flash-detectors.

Table 3. Lightning and growth

(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 is the yearly growth rate of 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 (log) 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 4A. Lightning and Internet diffusion - Controlling for initial levels of income and human capital

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Lightning	-3.57***	-3.57***	-3.63***	-1.21***	-2.30***	-2.51***	-3.10***
	[0.61]	[0.62]	[0.63]	[0.44]	[0.46]	[0.52]	[0.53]
(log) Real GSP per worker, 1991		9.95***	8.95**	8.99***	1.66	3.09	3.07
		[3.46]	[3.61]	[2.85]	[3.30]	[3.08]	[4.43]
Enrollment rate, 1991			-11.54				
			[14.57]				
High school degree or higher, 1990				71.04***			
				[9.86]			
Bachelor's degree or higher, 1991					0.86***		
					[0.14]		
College degree or higher, 1998						66.96***	
						[10.12]	
Graduate or professional degree, 1990							125.56***
							[45.86]
Constant	57.18***	-49.77	-28.33	-95.32***	20.97	7.28	15.33
	[0.72]	[37.19]	[44.27]	[31.10]	[34.28]	[32.29]	[45.65]
Observations	48	48	48	48	48	48	48
R-squared	0.38	0.45	0.46	0.73	0.66	0.64	0.54

Notes. OLS estimates. The dependent variable is the percentage of households with access to the Internet at home in 2003. Lightning is the (log) 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 4B. Lightning and Internet 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 manufac-turing 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)
Lightning	-1.21***	-1.20***	-1.20***	-1.30**	-1.22***	-0.90*	-1.29***	-1.22***	-1.39***	-1.38***	-1.25**	-1.07**	-1.05**	-1.29**	-1.19**	-1.07***	-0.89*
	[0.44]	[0.44]	[0.44]	[0.49]	[0.42]	[0.48]	[0.43]	[0.44]	[0.51]	[0.45]	[0.59]	[0.47]	[0.46]	[0.51]	[0.45]	[0.40]	[0.44]
(log) Real GSP per worker, 1991	8.99***	6.31*	8.55**	9.13***	11.58***	6.30*	7.48***	8.89***	8.02***	9.00***	9.08***	11.86***	10.12***	9.54***	9.70**	5.82**	3.87
	[2.85]	[3.58]	[3.58]	[2.88]	[3.36]	[3.26]	[2.51]	[2.99]	[2.78]	[2.84]	[3.20]	[3.25]	[2.97]	[2.98]	[3.90]	[2.84]	[3.40]
High school degree or higher, 1990	71.04***	73.91***	71.05***	74.82***	68.46***	76.43***	73.15***	72.51***	73.22***	78.65***	70.82***	60.48***	66.26***	71.32***	72.22***	78.05***	77.54***
	[9.86]	[10.14]	[9.97]	[9.84]	[10.82]	[10.98]	[10.20]	[11.11]	[10.26]	[13.60]	[10.25]	[10.23]	[11.89]	[10.21]	[10.92]	[9.77]	[9.24]
ADDITIONAL CONTROL		-29.17	-4.82	10.2	-1.64	-0.67*	0.63	12.36	-6.63	4.26	3.61	12.90**	-5.7	-8.63	-1.36	-56.37	67.60**
		[21.05]	[25.08]	[8.42]	[1.05]	[0.37]	[0.40]	[55.69]	[5.48]	[4.21]	[28.74]	[6.32]	[8.03]	[6.84]	[4.05]	[33.88]	[30.31]
Constant	-95.32***	-67.95*	-89.88**	-101.40***	-108.72***	-67.62*	-90.08***	-95.62***	-86.05***	-101.52***	-96.48***	-129.23***	-103.40***	-100.95***	-102.91**	-54.21	-89.61***
	[31.10]	[37.59]	[41.30]	[32.75]	[31.50]	[33.83]	[27.52]	[31.52]	[30.82]	[32.78]	[35.55]	[35.88]	[30.59]	[32.34]	[42.51]	[34.32]	[28.36]
Observations	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
R-squared	0.73	0.74	0.73	0.74	0.75	0.75	0.74	0.73	0.74	0.74	0.73	0.75	0.73	0.74	0.73	0.76	0.76

Notes. OLS estimates. The dependent variable is the percentage of households with access to the Internet at home in 2003. Lightning is the (log) 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

Table 5A. Lightning and computer diffusion - Controlling for initial levels of income and human capital

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Lightning	-3.68***	-3.67***	-3.56***	-1.40***	-2.13***	-2.74***	-3.26***
	[0.56]	[0.58]	[0.60]	[0.46]	[0.49]	[0.53]	[0.51]
(log) Real GSP per worker, 1977		2.40	2.81	-1.27	-2.82	-1.44	-1.39
		[3.87]	[4.24]	[3.02]	[3.00]	[3.20]	[3.42]
Enrollment rate, 1980			7.35				
			[17.82]				
High school degree or higher, 1980				47.65***			
				[8.76]			
Bachelor's degree or higher, 1977					4.47***		
					[0.73]		
College degree or higher, 1998						59.70***	
						[10.84]	
Graduate or professional degree, 1990							112.71***
							[35.25]
Constant	64.97***	39.4	28.51	44.79	41.57	65.37*	71.79*
	[0.72]	[41.23]	[53.08]	[31.95]	[31.36]	[34.08]	[36.05]
Observations	48	48	48	48	48	48	48
R-squared	0.43	0.43	0.43	0.63	0.65	0.61	0.52

Notes. OLS estimates. The dependent variable is percentage of households with a personal computer at home in 2003. Lightning is the (log) 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 5B. Lightning and computer diffusion - Additional controls

		Economy structure			Trade & Integration			Institutions			Religion	Race & ethnicity			Urbanization	Age structure	
Additional control:		Share of agriculture in GSP, 1977	Share of government in GSP, 1977	Share of manufacturing in GSP, 1977	(log) FDI per capita, 1981	(log) Agricultural exports per capita 1977	(log) Population, 1977	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, 1980	% black population, 1980	% Hispanic origin population, 1980	% urban population, 1980	% population 15 years or less, 1980	% population 15-64 years, 1980
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Lightning	-1.40***	-1.23**	-1.37***	-1.22**	-1.41***	-0.98*	-1.46***	-1.32***	-1.53***	-1.48***	-1.76***	-1.25***	-1.43***	-1.32***	-1.45***	-1.31***	-1.05**
	[0.46]	[0.50]	[0.48]	[0.47]	[0.48]	[0.51]	[0.51]	[0.43]	[0.49]	[0.50]	[0.58]	[0.40]	[0.51]	[0.44]	[0.47]	[0.43]	[0.49]
(log) Real GSP per worker, 1977	-1.27	-4.17	-0.48	-2.35	-0.77	-2.43	-2.6	-0.43	-1.78	-1.19	-0.81	0.97	-1.56	0.08	-3.18	-1.91	-4.45
	[3.02]	[3.56]	[3.13]	[2.67]	[3.37]	[2.90]	[3.78]	[3.46]	[2.85]	[3.14]	[3.34]	[3.38]	[3.61]	[3.07]	[3.81]	[2.85]	[3.25]
High school degree or higher, 1980	47.65***	51.62***	47.46***	56.43***	47.12***	51.51***	49.54***	43.34***	52.59***	51.64***	47.24***	40.43***	49.08***	51.08***	45.42***	48.82***	50.22***
	[8.76]	[9.60]	[8.45]	[9.11]	[9.41]	[9.38]	[8.72]	[10.66]	[9.27]	[9.95]	[8.95]	[10.37]	[11.27]	[8.74]	[8.60]	[8.70]	[8.74]
Additional control		-23.27	21.38	14.17**	-0.36	-0.57*	0.52	-53.62	-9.61	2.71	29.79	11.25	1.76	-16.51**	3.52	-23.92	50.54
		[14.52]	[20.85]	[6.72]	[0.70]	[0.29]	[0.58]	[62.71]	[6.56]	[4.50]	[27.30]	[7.92]	[10.78]	[7.03]	[3.83]	[38.65]	[50.59]
Constant	44.79	73.69**	33.44	47.24	42.17	56.56*	50.07	39.79	47.54	41.08	37.17	15.93	46.74	28.77	64.25	56.25*	43.49
	[31.95]	[36.21]	[34.36]	[28.32]	[33.58]	[30.29]	[35.53]	[34.27]	[30.40]	[33.80]	[36.31]	[37.64]	[35.60]	[32.76]	[39.42]	[33.30]	[30.93]
Observations	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
R-squared	0.63	0.64	0.64	0.67	0.63	0.65	0.64	0.64	0.65	0.63	0.64	0.65	0.63	0.67	0.64	0.64	0.65

Notes. OLS estimates. The dependent variable is percentage of households with a personal computer at home in 2003. Lightning is the (log) 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

Table 6. Lightning and Internet diffusion (controlling for cross sectional dependence)

	(1)	(2)	(3)
Lightning	-1.21***	-1.89**	-1.46**
	[0.44]	[0.71]	[0.55]
(log) Real GSP per worker, 1991	8.99***	5.80*	7.12***
	[2.85]	[3.07]	[2.60]
High school degree or higher, 1990	71.04***	91.49***	73.18***
	[9.86]	[14.39]	[10.26]
Constant	-95.32***	-79.30**	-77.34***
	[31.10]	[32.51]	[28.50]
Observations	48	48	48
R-squared	0.73	0.79	0.76
Regional dummies:	no	US Census Bureau	Major interconnections
		(4 regions)	NERC (3 regions)
H0: all reg dummies = 0 (p-value)		0.03	0.15

Notes. OLS estimates. The dependent variable is the percentage of households with access to the Internet in 2003. Lightning is the (log) average number of flashes per year per square km, measured by flash-detectors. The rest of the covariates are described in the Data Appendix. The set of regional dummies in column (2) is the US Census Bureau's regional division of the country (West, Midwest, Northeast, South), and the regional dummies in column (3) is the major interconnected power systems of the North American Electric Reliability Corporation, NERC (Western, Eastern, Texas). Robust standard errors in brackets. Asterisks ***, **, and * indicate significance at the 1, 5, and 10%, respectively.

Table 7. Lightning and computer diffusion (controlling for cross sectional dependence)

	(1)	(2)	(3)
Lightning	-1.40***	-2.10***	-1.62***
	[0.46]	[0.66]	[0.52]
(log) Real GSP per worker, 1977	-1.27	-1.8	-1.7
	[3.02]	[2.66]	[3.03]
High school degree or higher, 1980	47.65***	71.90***	53.48***
	[8.76]	[13.74]	[9.02]
Constant	44.79	30.21	44.36
	[31.95]	[27.38]	[32.65]
Observations	48	48	48
R-squared	0.63	0.71	0.69
Regional dummies:	no	US Census Bureau	Major interconnections
		(4 regions)	NERC (3 regions)
H0: all reg dummies = 0 (p-value)		0.03	0.07

Notes. OLS estimates. The dependent variable is the percentage of households with a personal computer at home in 2003. Lightning is the (log) average number of flashes per year per square km, measured by flash-detectors. The rest of the covariates are described in the Data Appendix. The set of regional dummies in column (2) is the US Census Bureau's regional division of the country (West, Midwest, Northeast, South), and the regional dummies in column (3) is the major interconnected power systems of the North American Electric Reliability Corporation, NERC (Western, Eastern, Texas). Robust standard errors in brackets. Asterisks ***, **, and * indicate significance at the 1, 5, and 10%, respectively.

Table 8. Growth, lightning, and IT

	(1)	(2)	(3)	(4)	(5)	(6)
(log) Real GSP per worker, 1991	-0.66	-0.82*	-0.99**	-0.76*	-0.92**	-1.19***
	[0.41]	[0.44]	[0.45]	[0.42]	[0.43]	[0.44]
Lightning	-0.16**			-0.09	-0.06	-0.09
	[0.08]			[0.10]	[0.09]	[0.09]
Computer presence, 2003		2.82**		1.72		-7.67
		[1.20]		[1.56]		[4.58]
Internet presence, 2003			3.32***		2.58*	9.65**
			[1.13]		[1.36]	[4.33]
Constant	8.57*	8.39*	10.19**	8.48*	9.85**	13.76***
	[4.40]	[4.52]	[4.57]	[4.45]	[4.44]	[4.79]
Observations	48	48	48	48	48	48
R-squared	0.15	0.15	0.19	0.17	0.20	0.24

Notes. OLS estimates. The dependent variable is the yearly growth rate of GSP per worker over the period 1991-2007. Computer presence is the % of households with a computer at home, and Internet presence is the % of households with access to Internet at home. Lightning is the (log) 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 9. Growth regressions with geographical and climate controls

GEOGRAPHY: (log)	Lightning (flashes/year/ sqkm)	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) Real GSP per worker, initial	-0.72	-0.72	-0.84*	-0.82*	-0.90*	-0.66	-0.66	-0.67	-0.86	-0.83*	-0.70
	[0.45]	[0.46]	[0.44]	[0.44]	[0.46]	[0.47]	[0.45]	[0.44]	[0.52]	[0.46]	[0.45]
GEOGRAPHY × $t_{78\text{-}87}$	0.07	0.05	1.06***	1.83***	-0.56	-0.41***	2.14**	0.89	-1.32	-0.36***	-0.2
	[0.10]	[0.28]	[0.20]	[0.38]	[0.89]	[0.14]	[0.83]	[0.54]	[0.86]	[0.08]	[0.91]
GEOGRAPHY × $t_{88\text{-}97}$	-0.07	0.15	0.25	0.24	-0.54	0.01	-0.95	-0.17	-0.28	-0.02	-0.03
	[0.08]	[0.25]	[0.26]	[0.44]	[0.72]	[0.10]	[0.77]	[0.43]	[0.54]	[0.09]	[0.83]
GEOGRAPHY × $t_{98\text{-}07}$	-0.22***	-0.12	0.08	-0.24	-1.99	0.19	-0.97	-0.33	0.002	0.07	0.73
	[0.08]	[0.23]	[0.18]	[0.32]	[1.22]	[0.43]	[0.70]	[0.41]	[0.70]	[0.07]	[0.55]
Observations	144	144	144	144	144	144	144	144	141	144	144
R-squared	0.15	0.11	0.23	0.21	0.13	0.16	0.15	0.13	0.14	0.23	0.11

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. All regressions include a constant and a full set of time-dummies. All geographic/climate variables are (log) annual averages taken over periods of 10 years, described in the Data Appendix. Lightning is the (log) average number of flashes per year per square km, measured by flash-detectors. Robust standard errors in brackets, adjusted for clustering at the state level. Asterisks ***, **, and * indicate significance at the 1, 5, and 10%, respectively.

Table 10. Growth regressions with geographical and climate controls, conditional on lightning

GEOGRAPHY: (log)		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) Real GSP per worker, initial	-0.72	-0.80*	-0.92**	-0.86*	-0.84*	-0.68	-0.65	-0.67	-0.85	-1.04**	-0.75
	[0.45]	[0.47]	[0.43]	[0.43]	[0.48]	[0.46]	[0.45]	[0.45]	[0.52]	[0.47]	[0.46]
Lightning × t_{78-87}	0.07	0.08	-0.07	-0.06	0.12	-0.17	-0.001	0.10	0.11	-0.15	0.09
	[0.10]	[0.11]	[0.14]	[0.12]	[0.12]	[0.14]	[0.14]	[0.12]	[0.11]	[0.12]	[0.13]
Lightning × t_{88-97}	-0.07	-0.13	-0.11	-0.1	-0.06	-0.07	-0.04	-0.07	-0.06	-0.1	-0.12
	[0.08]	[0.08]	[0.09]	[0.10]	[0.08]	[0.09]	[0.09]	[0.08]	[0.07]	[0.10]	[0.09]
Lightning × t_{98-07}	-0.22***	-0.29***	-0.25***	-0.22***	-0.21**	-0.23***	-0.21**	-0.24***	-0.23***	-0.24**	-0.29***
	[0.08]	[0.09]	[0.08]	[0.08]	[0.09]	[0.08]	[0.08]	[0.08]	[0.08]	[0.09]	[0.10]
GEOGRAPHY × t_{78-87}		-0.06	1.12***	1.95***	-0.95	-0.58***	2.15**	0.97*	-1.47*	-0.43***	0.29
		[0.31]	[0.26]	[0.45]	[0.98]	[0.18]	[1.03]	[0.55]	[0.84]	[0.09]	[1.12]
GEOGRAPHY × t_{88-97}		0.33	0.36	0.44	-0.45	-0.03	-0.83	-0.22	-0.2	-0.08	-0.69
		[0.26]	[0.27]	[0.52]	[0.77]	[0.11]	[0.83]	[0.42]	[0.51]	[0.11]	[1.00]
GEOGRAPHY × t_{98-07}		0.37	0.25	-0.04	-0.4	-0.16	-0.28	-0.52	0.33	-0.04	-0.86
		[0.27]	[0.20]	[0.28]	[1.22]	[0.42]	[0.86]	[0.34]	[0.60]	[0.08]	[0.71]
Observations	144	144	144	144	144	144	144	144	141	144	144
R-squared	0.15	0.17	0.29	0.26	0.16	0.22	0.19	0.19	0.19	0.29	0.16

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. All regressions include a constant and a full set of time-dummies. All geographic/climate variables are (log) annual averages taken over periods of 10 years. Lightning is the (log) 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 11. Growth regressions with historical controls (geography and institutions)

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) Real GSP per worker, initial	-0.72	-0.71	-0.73	-0.68	-0.87*	-0.68	-0.72*	-1.23***	-0.73*	-1.03**	-0.67
	[0.45]	[0.44]	[0.45]	[0.45]	[0.45]	[0.45]	[0.43]	[0.43]	[0.40]	[0.43]	[0.45]
Lightning × $t_{78\text{-}87}$	0.07										
	[0.10]										
Lightning × $t_{88\text{-}97}$	-0.07										
	[0.08]										
Lightning × $t_{98\text{-}07}$	-0.22***										
	[0.08]										
HISTORY × $t_{78\text{-}87}$		-2.95***	-0.004	1.10**	0.74***	1.80*	0.70***	-0.43**	-0.69***	0.65***	-1.90
		[0.68]	[0.01]	[0.54]	[0.20]	[0.91]	[0.18]	[0.21]	[0.19]	[0.20]	[10.49]
HISTORY × $t_{88\text{-}97}$		-0.67	-0.01	-0.61	0.29	-1.21*	0.12	-0.55***	-0.26	0.45*	-5.36
		[0.93]	[0.01]	[0.43]	[0.26]	[0.68]	[0.19]	[0.16]	[0.17]	[0.23]	[8.78]
HISTORY × $t_{98\text{-}07}$		0.84	-0.005	-0.69*	0.05	-1.14**	-0.05	-0.36**	0.02	0.36	-15.99**
		[0.71]	[0.01]	[0.36]	[0.18]	[0.53]	[0.18]	[0.17]	[0.16]	[0.29]	[6.84]
Observations	144	144	144	144	144	144	144	144	144	144	144
R-squared	0.15	0.18	0.11	0.15	0.19	0.16	0.20	0.21	0.21	0.15	0.13

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. All regressions include a constant and a full set of time-dummies. Lightning is the (log) average number of flashes per year per square km, measured by flash-detectors. All HISTORY variables 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 12. Growth regressions with historical controls (geography and institutions) and lightning

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) Real GSP per worker, initial	-0.72	-0.78*	-0.700	-0.65	-0.96**	-0.66	-0.73	-1.20***	-0.74*	-1.02**	-0.67
	[0.45]	[0.43]	[0.46]	[0.46]	[0.44]	[0.47]	[0.43]	[0.44]	[0.40]	[0.44]	[0.46]
Lightning × $t_{78\text{-}87}$	0.07	-0.06	0.14	-0.06	-0.03	-0.05	0.06	0.12	0.04	0.07	0.11
	[0.10]	[0.13]	[0.11]	[0.13]	[0.13]	[0.12]	[0.10]	[0.10]	[0.10]	[0.10]	[0.11]
Lightning × $t_{88\text{-}97}$	-0.07	-0.11	-0.04	-0.01	-0.11	0.01	-0.07	-0.01	-0.08	-0.06	-0.05
	[0.08]	[0.09]	[0.07]	[0.09]	[0.09]	[0.08]	[0.08]	[0.09]	[0.08]	[0.08]	[0.08]
Lightning × $t_{98\text{-}07}$	-0.22***	-0.23**	-0.33***	-0.23**	-0.25***	-0.22**	-0.22***	-0.20**	-0.22***	-0.22***	-0.19*
	[0.08]	[0.09]	[0.08]	[0.09]	[0.08]	[0.09]	[0.08]	[0.09]	[0.08]	[0.08]	[0.10]
HISTORY × $t_{78\text{-}87}$		-3.18***	-0.01	1.31**	0.77***	2.05**	0.70***	-0.47**	-0.68***	0.66***	-7.63
		[0.87]	[0.01]	[0.63]	[0.24]	[1.02]	[0.19]	[0.21]	[0.20]	[0.21]	[11.70]
HISTORY × $t_{88\text{-}97}$		-1.16	-0.004	-0.58	0.39	-1.24	0.12	-0.55***	-0.27	0.44*	-2.60
		[1.06]	[0.01]	[0.50]	[0.29]	[0.78]	[0.19]	[0.18]	[0.17]	[0.24]	[9.04]
HISTORY × $t_{98\text{-}07}$		-0.15	0.02***	0.07	0.25	-0.03	-0.03	-0.27	-0.01	0.33	-5.79
		[0.97]	[0.01]	[0.44]	[0.22]	[0.68]	[0.16]	[0.18]	[0.15]	[0.28]	[8.42]
Observations	144	144	144	144	144	144	144	144	144	144	144
R-squared	0.15	0.22	0.17	0.18	0.24	0.19	0.24	0.25	0.25	0.20	0.16

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. All regressions include a constant and a full set of time-dummies. Lightning is the (log) average number of flashes per year per square km, measured by flash-detectors. All HISTORY variables 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 13. Growth regressions with integration controls and lightning

INTEGRATION: (log)		Agricultural exports per capita	FDI per capita	Agricultural exports per capita	FDI per capita
	(1)	(2)	(3)	(4)	(5)
(log, initial) Real GDP per worker	-0.72	-1.02**	-0.41	-0.99**	-0.42
	[0.45]	[0.44]	[0.55]	[0.44]	[0.56]
Lightning × $t_{78\text{-}87}$	0.07			0.15*	0.07
	[0.10]			[0.09]	[0.11]
Lightning × $t_{88\text{-}97}$	-0.07			-0.04	-0.06
	[0.08]			[0.08]	[0.08]
Lightning × $t_{98\text{-}07}$	-0.22***			-0.23***	-0.22***
	[0.08]			[0.08]	[0.07]
INTEGRATION × $t_{78\text{-}87}$		-0.18***	-0.12	-0.20***	-0.13
		[0.05]	[0.16]	[0.05]	[0.16]
INTEGRATION × $t_{88\text{-}97}$		-0.14**	-0.13	-0.14**	-0.11
		[0.06]	[0.18]	[0.06]	[0.19]
INTEGRATION × $t_{98\text{-}07}$		-0.01	-0.42***	0.01	-0.42***
		[0.05]	[0.12]	[0.05]	[0.13]
Observations	144	144	144	144	144
R-squared	0.15	0.22	0.13	0.28	0.18

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. All regressions include a constant and a full set of time-dummies. Lightning is the (log) 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 A1. Tests for whether lightning is a constant plus white noise

	Breusch-Godfrey test			Runs test	
	test-statistic	p-value	No. lags[a)]	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.
a) Lags selected by Schwarz's information criteria.