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WORLD TECHNOLOGY USAGE LAGS

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### **ABSTRACT**

We present evidence on the differences in the intensity with which ten major technologies are used in 185 countries across the world. We do so by calculating how many years ago these technologies were used in the U.S. at the same intensity as they are used in the countries in our sample. We denote these time lags as technology usage lags and compare them with lags in real GDP per capita. We find that (i) technology usage lags are large, often comparable to lags in real GDP per capita, (ii) usage lags are highly correlated with lags in per-capita income, and (iii) usage lags are highly correlated across technologies. The productivity differentials between the state of the art technologies that we consider and the ones they replace combined with the usage lags that we document, lead us to infer that technology usage disparities might account for a large part of cross-country TFP differentials.

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## *1. Introduction*

How large are cross-country differences in technology? Are they comparable to cross-country differences in income per capita?

A substantial literature<sup>1</sup> has tried to answer these two questions by constructing indirect measures of technology based on the Solow residual. This approach, however, suffers from the problem that the Solow residual captures not only differences in technology, but also variation in capacity utilization (Basu, 1995), labor hoarding (Burnside et al., 1995), and the inefficiencies of the economy (Weil, 2005, ch.10).

Concerning the second question, Weil (2005, Ch. 15) argues that technology adoption lags are most likely much smaller than per-capita income lags; if technology were responsible for the cross-country variation in income per capita and grew at an annual rate of 2 percent a year,<sup>2</sup> India would currently be using technologies that the U.S. employed 100 years ago. This is obviously not the case, since producers in India also use recent technologies such as computers and cell phones.

Weil correctly highlights the importance of using direct measures of technology to answer the questions that motivate this paper. However, his argument ignores the importance of cross-country variation in the intensity of adoption of new technologies.

That is, most discussions of technology adoption differentials, including Weil's, focus on whether or not, or what fraction of users, have adopted a technology. This is the extensive margin of adoption. This ignores, however, what intensity the adopters use the technology, i.e. the intensive margin.

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<sup>1</sup> Klenow and Rodríguez-Clare (1997), Hall and Jones (1999), and Benhabib and Spiegel (2005) among others.

<sup>2</sup> This is the rate necessary to sustain the growth rate in labor productivity observed during the last 120 years in the U.S.

Hence, it is not only relevant whether computers and cell phones are being used in India, but also how many of them are used.

An older literature initiated by Griliches (1957) and Mansfield (1961) directly measures technology adoption by considering the fraction of the potential adopters using a technology. Calculating this type of measure requires micro-level data at the producer level which is not available for a broad sample of countries and technologies.<sup>3</sup> Just like Weil's argument, this approach also does not capture the intensity with which each adopter uses the technology. As shown by Clark (1988), this margin may be critical to explain cross-country differences in labor productivity.

In this paper, we explore the questions posed above by constructing per-capita usage intensity measures of technology, including kWh of annual electricity production per capita and personal computers per capita. These measures include both the extensive and the intensive margins of technology adoption. Furthermore, their construction only requires aggregate data that is available for a wide sample of countries and technologies.

We consider ten technologies that all share three properties. They are (i) technologies with important roles in production, that, at the point in time that for which we consider them, (ii) represent the cutting edge in the production of a particular good or service, and (iii) for which we have data for a wide range of countries.<sup>4</sup>

Rather than analyzing the level of the technology usage measures, we analyze time lags with respect to the U.S. The usage lag of technology  $x$  in country  $c$  at year  $t$  is defined as the answer to the following question: How many years before year  $t$  did the United States last have a usage intensity of technology  $x$  that country  $c$  has in year  $t$ ?

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<sup>3</sup> The Federal Reserve Bank of Dallas (1996) has an informative description of the historical diffusion patterns of consumer technologies in the U.S.

<sup>4</sup> The technologies we consider are the subset of those introduced in Comin, Hobijn, and Rovito (2006).

For example, the amount of kWh of electricity produced in Uruguay in 1990 was last observed in the United States in 1949. Thus, the electricity usage lag in Uruguay in 1990 is 41 years. Similarly, the number of personal computers per capita in Spain in 2002 was comparable to that in the United States in 1989. Hence, the 2002 PC usage lag of Spain is 13 years.

Usage lags make measures of technology adoption comparable across technologies and also with income per capita. In addition, by considering the intensive margin of adoption, they enable us to shed light on Weil's claim.

Our analysis uncovers three main facts: (i) Technology usage lags are large, often comparable to lags in real GDP per capita; (ii) usage lags are highly correlated across countries with lags in per-capita income, and (iii) usage lags are highly correlated across technologies.

## *2. The concept of time lags*

We further explain the concept of time lags with an additional example. Consider Figure 1. It plots real GDP per capita as a fraction of the 2003 U.S. level (in log-scale) for the U.S. as well as China, France, Japan, and Mexico. Using this figure we can answer the following question: how many years before the year 2000 did the United States last have the real GDP per capita that China had in 2000?

When we look at Figure 1, we see that the U.S. last passed China's 2000 level of GDP per capita in 1894, 106 years before 2000. Similarly, in 2000 the U.S. led Mexico by 60 years and France and Japan by 14.<sup>5</sup>

More formally, let  $X_{j,t}$  be the usage level of a given technology in country  $j$  at time  $t$ . We compare this observation with the historical time series for the United States. Let this series be given by  $\{X_{US,s}\}$  where  $s$  indexes the observations. These are not necessarily consecutive observations because of

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<sup>5</sup> Jovanovic (2006b) also considers this type of time lags in a theoretical model of endogenous growth and technology adoption.

missing data in the U.S. historical time series. Let  $S$  denote the set of observations available in the historical time series for the United States.

We define the following two observations in the time series for the U.S. The first is the last time the U.S. passed level  $X_{j,t}$ . That is

$$\bar{s} = \arg \min_{s \in S} \{s | X_{US,s'} \geq X_{j,t} \text{ for all } s' \in S \text{ and } s' \geq s\} \quad (1)$$

The second is the last time the U.S. recorded a technology usage level lower than  $X_{j,t}$ . That is

$$\underline{s} = \arg \max_{s \in S} \{s | X_{US,s} \leq X_{j,t}\} \quad (2)$$

Because of these definitions, we know that observation  $\bar{s}$  is the one after observation  $\underline{s}$  in the U.S. historical time series.

We impute the time that the U.S. last had the technology usage level  $X_{j,t}$ , say  $\tau$ , by linear interpolation. That is, we calculate

$$\tau = \left( \frac{X_{t,j} - X_{US,\underline{s}}}{X_{US,\bar{s}} - X_{US,\underline{s}}} \right) \bar{s} + \left( \frac{X_{US,\bar{s}} - X_{t,j}}{X_{US,\bar{s}} - X_{US,\underline{s}}} \right) \underline{s} \quad (3)$$

The technology usage lag between the U.S. and country  $j$  at time  $t$  is then given by  $t - \tau$ .

The analysis of time lags has two major advantages over that of disparities in technology usage levels across countries.

First, time lags are independent of the units of measurement of the variables considered. This flexibility is important when one aims to consider a broad range of statistics and compare them across countries and technologies, as we do for measures of technology usage here.

Second, the calculation of these lags does not require a very long time series for countries other than the U.S. It only requires a long historical time series for the U.S.

A couple of practical details are relevant for the calculation of the time lags. Sometimes, the U.S. historical time series does not go back so far as to include the invention date of the technology. We initialize the U.S. historical time series by setting  $X_{US, invention\ year} = 0$ . The invention years that we use are described in Appendix A. GDP, however, does not have an invention date. For GDP we use Maddison's (2007) historical time series of U.S. GDP per capita, which goes back to 1600.

For some countries, we find right-truncated lags in GDP per capita because they have GDP per capita levels lower than that of the U.S. in 1600. We have this problem for only a very limited number of Sub-Saharan African countries, including Guinea-Bissau and Botswana in 1950 and Zaire in 1990 and 2000. We also find some cases in which our technology usage lags are censored because the U.S. never achieves the level  $X_{j,t}$ . In this case the U.S. is not the technological leader.<sup>6</sup>

The number of censored technology usage lags in our sample is so small, though, that these censored observations do not affect the gist of our results.

### *3. Real GDP per capita lags*

#### *Size of real GDP lags*

Differences in standards of living across the world are very large. For example, U.S. real GDP per capita in 2000 was almost 19 times higher than the average over the continent of Africa. For the poorest country in the world, which in 2000 was Zaire, this ratio is almost 130! By comparison, U.S. real GDP per capita in 2000 was 23 times higher than it was in 1820.

Our time lag measures allow us to translate these differences across countries into years behind the United States. Figure 2 shows the time lags in real GDP per capita for all countries in the world in

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<sup>6</sup> This is particularly relevant for our results for cell phones in 2002, as can be seen from the many zero lags depicted in Figure 7. These lags are zero because 2002 is the last year for which we have data for the U.S., and the U.S. is not the global leader in cell phone adoption.

2000. As can be seen from the figure, most of the world population is living in countries with real GDP per capita levels that have not been observed in the United States in the post World War II era. Moreover, most of Sub-Saharan Africa, as well as Afghanistan and Mongolia, have per-capita income levels that have not been observed in the United States since 1820.

#### *Catch-up in GDP lags*

After documenting the magnitude of the per-capita income lags, it is natural to explore their dynamics. One way to do this is by studying the relationship between the change in the per-capita GDP lag between 1950 and 2000 and the initial lag in 1950. Figure 3 shows this relationship.

As can be seen from the figure, the countries that started off lagging the U.S. by the most years tended to have a bigger decrease (negative change) in their lag, suggesting that, on average, they caught up with the U.S. more quickly than the countries that were relatively richer in 1950.

For example, Ireland's GDP per capita lag was 56 years in 1950 and 13 years in 2000. Thus, its change was -43 years. This suggests that over the period 1950 through 2000, Ireland's GDP per capita increased by the same amount as the U.S.'s GDP per capita over the period 1894 through 1987. Some additional countries with big leaps forward during the last five decades of the last century include Botswana, from more than 350 to 100 years; China, from 316 to 106 years; South Korea, from 183 to 34 years; and Taiwan, from 172 to 24 years.

Not all countries saw their GDP lags decrease over the 1950 to 2000 period. Some countries, including some of the poorer nations, like Zimbabwe, Mozambique, and Ecuador, saw their distance from the U.S. increase by two decades or more. Argentina is also an interesting case, with its GDP lag relative to the U.S. increasing from 16 years in 1950 to 59 years in 2000.

To formalize this analysis, we estimate a regression of the 1950-2000 change in the real GDP lag of a country on its initial 1950 real GDP lag for a sample of 138 countries. The regression results are



$$\Delta \text{GDP lag}_{i,1950-2000} = \underset{(9.95)}{16.61} - \underset{(0.06)}{0.25} \text{GDP lag}_{i,1950}, \quad R^2 = 0.12, \quad i = 1, \dots, 138$$

and show that the GDP lags became significantly smaller for countries that started off more years behind the U.S. than for countries that started closer. The initial (1950) GDP lags explain 12% of the cross-country variation in the reduction in GDP lags relative to the U.S. over the second half of the 20<sup>th</sup> century.

This result may seem to be in sharp contrast with standard cross-country convergence analyses that do not find unconditional convergence in per-capita income, such as Barro and Sala-i-Martin (1992). The reason for this discrepancy is that we are asking a different question than the convergence literature.

The convergence literature considers whether countries that had relatively low per-capita GDP levels in 1950 grew faster than countries with higher levels of per-capita GDP. Our convergence analysis considers whether countries with relatively low per-capita GDP levels in 1950 grew faster in the 1950-2000 period than the U.S. did in the 50 years after it had the same per-capita GDP level as the countries in 1950.

This somewhat subtle, but important, difference means that our regression does not compare the countries over the same period in history but, instead, compares the countries at similar points in their per-capita GDP paths. This analysis offers a new perspective on the development process that allows us to understand whether it takes longer, on average, for currently developing economies to become developed and enjoy a sustained growth rate in per-capita income than that it took for the U.S. during its development period.

Hence, the convergence regression presented here compares the growth patterns of economies at a similar development stage rather than during a similar time period. Our analysis from this point of

view offers an illuminating conclusion: on average, it takes less time for currently developing economies to achieve development than that it took for the U.S.

This different perspective on the convergence question allows us to reconsider the predictions of different growth models. In particular, existence of the type of catch-up in real GDP lags documented here and the absence of unconditional convergence in conventional growth regressions suggest that real GDP dynamics are more consistent with the model presented in Lucas (2000) than with the dynamics implied by the neoclassical growth model, on which Barro and Sala-i-Martin (1992) base their analysis.

Lucas (2000) provides a model, based on Tamura (1996), of take off where countries are in stagnation and there is a random variable that determines when each country will start growing. When they start growing, they catch up with the countries that started the growth process earlier.

#### *From GDP lags to technology usage lags*

There is an extensive literature that tries to find the main sources of the cross-country differences in per-capita GDP levels. This literature is mainly based on the assumption that GDP is produced with two factors of production, namely capital and labor, and that these production factors are used with a particular level of efficiency, called total factor productivity (TFP), that varies across countries. Much of the evidence, as in Lucas (1990), Klenow and Rodríguez-Clare (1997), and Hall and Jones (1999), suggests that the majority of per-capita GDP differences come from differences in TFP, rather than from differences in the capital per worker used in production.

What causes cross-country disparities in TFP levels is a controversial topic in economics.<sup>7</sup> One way of thinking of TFP differentials is to decompose them into two parts. The first part consists of the cross-country differential in TFP levels common to all technologies that are in use. The second part

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<sup>7</sup> See Prescott (1997) for a discussion of why a theory that explains such differences is crucial to explain cross-country differences in per-capita income levels.

reflects the cross-country TFP differentials due to differences in the intensity of use of cutting-edge technologies that embody a higher level of productivity than older technologies.

This second source of TFP differentials may reflect cross-country differences in adoption costs that prevent modern technologies from being used, as in Parente and Prescott (1994,1999) and Chari and Hopenhayn (1991), or from differences in the costs of implementing technologies that result in newer technologies being used below their potential productivity level, as in Jovanovic (2006b) and Comin and Hobijn (2007).

In what follows, we present evidence that indicates that a significant part of cross-country differentials in TFP and per-capita income is driven by cross-country differences in the intensity of adoption of new technologies.

#### *4. Technology usage lags*

For our analysis of technology usage lags we use data on ten technologies from the Cross-country Historical Adoption of Technology (CHAT) data set introduced in Comin, Hobijn, and Rovito (2006). The technologies we consider are all the technologies that satisfy the following three criteria. First, they are mainly production technologies. Second, at the point in time for which we perform our analysis, they are cutting-edge technologies in that they are much more productive than other existing technologies that might be used to produce a similar good or service. Third, for the reference year for which we do our analysis, data on technology usage is available for a large sample of countries (at least 95). This requirement results in more meaningful global cross-country comparisons.

The ten technologies can be classified in five broad categories (technologies in parentheses): *(i)* electricity (electricity production), *(ii)* information technologies (internet and PCs), *(iii)* communication technologies (telephones and cell phones), *(iv)* transportation technologies (cars, trucks, plane

passengers transport, and plane cargo transport), and (*v*) agricultural technologies (tractors). Appendix A contains a description of these technologies, our data sources, the year in which we measure the technology, and the invention dates we use for the calculation of the usage lags. Just as for real GDP, we measure the intensity of usage of these technologies in per-capita terms.

All of these technologies satisfy the three criteria described above and, in particular, the use of each of them is associated with significant increases in productivity. Comin and Hobijn (2005) document the large productivity gains associated with the use of PCs, cell phones, telephones, cars, trucks, and planes. These productivity increments range from 1/3 for cell phones to many orders of magnitude for PCs.

The use of electricity as a power source led to significant increases in productivity. David (1990) estimates that “approximately half of the 5 percentage point acceleration recorded in the aggregate TFP growth rate of the U.S. manufacturing sector during 1919-29 (compared with 1909-19) is accounted for ... by the growth in manufacturing secondary electric motor capacity during that decade.”

Many growth accounting studies, including Oliner and Sichel (2000), suggest that information technology, in large part driven by the internet, has led to surge in U.S. productivity growth in the second half of the 1990s.

For tractors, Easter, Abel, and Norton (1977) estimate the marginal product of various factors of production using the value of wheat produced and the extent to which each input was used in 73 Indian districts. During the period 1967-69 they find that the marginal product of tractors is over 1000 times larger than the marginal product of work animals and over 2200 times larger than the marginal product of labor.

Figures 4, 5, 6, and 7 depict the technology usage lags of the ten technologies in our sample versus those of real GDP per capita. Figure 4 compares the 1970 electricity, tractors, and telephone usage lags with the 1970 real GDP per capita lags. Figures 5 and 6 do the same for the 1990 usage lags in

transportation technologies. Figure 7 shows the 2002 cell phone, PCs, and internet usage lags plotted against the 2000 real GDP per capita lags.

The first conclusion from these figures is the following.

*Conclusion 1: Cross-country disparities in technology usage lags are very large*

As can be seen from Figure 4, for countries with real GDP per capita lags smaller than 50 years in 1970, technology usage lags in electricity, tractors<sup>8</sup>, and telephones were generally at least as high as GDP lags. Moreover, countries with 1970 real GDP per capita levels comparable to those in the pre-World War I U.S. also largely have pre-World War I levels of technology usage in electricity and road transportation.

To put this in perspective, the countries that lagged the U.S. by more than 50 years in electricity production in 1970 are countries where electricity production in 1970 was not enough to light one 60-watt light bulb per person continuously.

The results for road transportation, reported in Figure 5, are similar. In 1990, 70 out of the 112 countries for which we have data had levels of car usage comparable to or lower than those in the U.S. in 1908 (technology usage lag of 82). It was in 1908 that Henry Ford sold his first Model T, which is generally considered the car that “put America on wheels”. For trucks, there are 24 countries with lags bigger than 82 years. Moreover, virtually all countries with real GDP per capita levels in 1990 that have not been observed in the U.S. since the start of World War II also have road transportation lags that are bigger than 50 years.

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<sup>8</sup> We also calculated our results for tractors per member of the agricultural labor force. These results turned out to be very similar to the ones reported here in per-capita terms. They, however, covered a much smaller sample of countries because of the limited sample of countries for which agricultural labor force statistics are available. Thus, we present only the results for tractors per capita here.

For aviation, in Figure 6, we find slightly smaller technology lags. This difference largely reflects the fact that, although modern airplanes were invented by the Wright brothers in 1903, it was only after 1945 that civil aviation really took off, even in the U.S.

Figure 7 focuses on three more modern technologies: PCs, cell phones, and the internet. We find that, in 2000, PCs are used at an intensity level in most countries that predates the U.S. 1990 level. In fact, one third of the countries in our sample have an intensity of PC usage that is less than that in the United States in 1981, the year that the first IBM-PC was introduced.

In contrast, the internet and cell phones are technologies in which the U.S. is not the leader in their intensity of usage. In 2002, Australia, Canada, Denmark, Singapore, and Sweden had more internet users per capita than the U.S. At the same time, 51 out of the 123 countries for which we have data had internet usage levels in 2002 that have not been observed in the U.S. since the introduction of web browsers in 1993. The U.S. is also not the leader in cell phone usage. In 2002, cell phone usage in 32 out of the 145 countries in our sample exceeded that in the U.S. These countries include, among others, almost all the nations of Western Europe, Australia, New Zealand, Japan, Singapore, South Korea, as well as the Czech Republic and Slovenia.

These large cross-country dispersions in technology usage lags, together with the substantial productivity improvements associated with the use of the new technologies in our sample, indicate that cross-country variation in the use of state-of-the-art technologies may be responsible for a significant part of the cross-country variation in per-capita income and TFP.

Besides the actual levels of the usage lags, we can also study the cross-country relation between technology usage and per-capita GDP time lags.

*Conclusion 2: Technology usage lags are highly correlated with real GDP per capita lags*

This property is already fairly evident from Figures 4, 5, 6, and 7. For all the technologies depicted in these figures, the average technology usage lag is increasing in the real GDP lag. The actual correlations that this conclusion is based on are listed in the “correlations and joint sample sizes” part of Table 1. The first four rows of this part of the table list the correlations of the technology usage lags with real GDP lags in 1950, 1970, 1990, and 2000.

When we compare the technology usage lags with the real GDP lags in the corresponding years, as is also done in Figures 4, 5, 6, and 7, we find that the average correlation of technology usage lags with GDP lags is 0.76. The minimum is cargo aviation at 0.66. The maximum is the internet with 0.87. These correlations are high, in spite of the non-linear relationship between GDP lags and technology lags, which is evident from Figures 4, 5, 6, and 7.<sup>9</sup>

For electricity we not only find a high correlation in the levels of usage lags with those of real GDP, but also in the changes in each of the lags between 1950 and 1990. This relationship can be seen from Figure 8. This figure has only three observations in the lower right-hand quadrant, which illustrates that all (but three) countries that were catching up with the United States in terms of electricity production from 1950 to 1990 reduced their per-capita income lags as well. The regression line, based on a sample of 95 countries is as follows:

$$\Delta \text{Electricity lag}_{i,1950-2000} = 12.77 + 0.17 \Delta \text{GDP lag}_{i,1950-2000}, \quad R^2 = 0.27, \quad i = 1, \dots, 95$$

(1.31)      (0.03)

This result shows that countries that caught up more than average with the U.S. in terms of GDP lags also did so in terms of electricity lags. It suggests that electrification, as a general purpose technology, played a crucial part in economic development in the last century.

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<sup>9</sup> This observation is consistent with (1) a positive correlation between levels of per-capita GDP and technology usage documented in Comin and Hobijn (2004) and Comin, Hobijn, and Rovito (2006), (2) the positive partial correlations of per-capita GDP and PC usage found by Caselli and Coleman (2001), and (3) per-capita GDP and the timing of adoption of real time gross settlement systems for interbank payments found by Bech and Hobijn (2006).

It is often argued that, after electricity, the computer is the next general purpose technology.<sup>10</sup> It turns out that the countries that lagged the U.S. the most in electricity in the *middle* of the 20<sup>th</sup> century also tend to be the countries that lag the U.S. the most in PCs at the *end* of the 20<sup>th</sup> century. This property can be seen from the technology usage lag correlation between electricity in 1950 and the internet in 2002, which equals 0.81, and in the correlation between electricity in 1950 and PCs in 2002, which equals 0.82.

This finding holds more generally.

*Conclusion 3: Usage lags are positively correlated across all technologies in our sample*

This positive correlation is apparent for the technologies that are jointly plotted in Figures 4, 5, 6, and 7. The correlations across all technologies can be found in the “correlations and joint sample sizes” part of Table 1. The average correlation across technology lags is 0.79, while the minimum is 0.51 for cargo aviation and tractors, and the maximum is 0.93 for electricity in 1970 and 1990. Considering only correlations between different technologies, the maximum is also 0.93, between cars in 1990 and telephones in 1970.

One interesting implication of this conclusion is that the positive correlation in usage lags is not only observed contemporaneously. It is also true between lags for different technologies decades apart. Skinner and Staiger (2005) document similar correlations in cross-state adoption patterns of several, seemingly unrelated, technologies over time for U.S. states.

Some other interesting dynamics are also evident in the technology usage lags. As Figures 4, 5, 6, and 7 illustrate, many developing countries lag the U.S. much less in the use of the technologies that have driven a large part of economic growth in industrialized countries in recent decades, like mobile communications and information technology, than in older technologies such as electricity or cars. It is,

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<sup>10</sup> David (1990) puts this claim into a historical perspective.



however, too early to tell if this result is driven by the low age of these new technologies, which limits the size of the gaps that can currently be observed. If these results were to persist as these technologies age, though, it would suggest that usage lags have become smaller for more recent technologies, which would indicate an increase in the rate of international technology diffusion.

## *5. Conclusion*

The U.S. leads the world in the intensity of use of a broad range of technologies. For many countries, the degree to which they use various technologies, including electricity, cars, trucks, and phones, lags the technology usage level in the U.S. by several decades.

The evidence on usage lags, that measure how many years ago the ten technologies that we consider were used in the U.S. at the same intensity as they are used in the countries in our sample, that we presented in this paper uncovers three main regularities.

First, usage lags are sizeable. Second, usage lags are highly correlated across technologies. Third, technology usage lags are also highly correlated with the level of economic development of a country, as measured by per-capita income.

The productivity differentials between the state of the art technologies that we consider and the ones they replace combined with the usage lags that we document, lead us to infer that technology usage disparities might account for a large part of cross-country TFP differentials. If so, then (the intensity of) adoption of new technologies is a key mechanism for understanding the development process.

Our analysis of real GDP per capita lags uncovers a type of catch-up in GDP lags that suggests that real GDP dynamics is more consistent with Lucas (2000) than with the neoclassical growth model analyzed by Barro and Sala-i-Martin (1992).

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## *A. Data: sources and definitions*

**Countries:** Our sample consists of 185 countries. Unfortunately, we do not have data for all countries for all years. Because of this we have chosen the years for which we present our results to make the coverage of our sample as broad as possible.

**Description of technologies:** The particular technologies that we use are measured and classified as follows. For those technologies for which we use more than one source, we use the merged time series from Comin, Hobijn, and Rovito (2006).

### **Standard of living**

- **Real GDP per capita:** Gross domestic product measured in 1990 International Geary-Khamis dollars. *Source:* Maddison (2007).

### **Electricity**

- **Electricity:** Gross output of electric energy (inclusive of electricity consumed in power stations) in kWh per capita. *Invention date:* 1882, when Edison built first DC generator and used the electricity it produced to illuminate Pearl St. in New York City. *Source:* World Bank (2007) and Mitchell (1998a,b,c).

### **Information technologies (IT)**

- **Internet users:** Number of people with access to the worldwide network per capita. *Invention date:* 1983, when TCP-IP is introduced as the standardized internet protocol. *Source:* World Bank (2007).
- **Personal computers:** Number of self-contained computers, designed for use by one person, per capita. *Invention date:* 1973, with the first application of Intel microprocessors in computers. *Source:* World Bank (2007).

### **Communication technologies (CT)**

- **Cell phones:** Number of portable cell phones per capita. *Invention date:* 1973, when Martin Cooper of Motorola placed first public telephone call on a portable cellular phone. *Source:* World Bank (2007).

- **Telephones:** Number of mainline telephone lines connecting a customer's equipment to the public telephone network, as of year end, per capita. *Invention date:* 1876, when the telephone invented by Alexander Graham Bell. *Source:* World Bank (2007) and Mitchell (1998a,b,c).

### Transportation technologies

- **Aviation - cargo:** Civil aviation ton-KM of cargo carried on scheduled services by companies registered in the country concerned per capita. *Invention date:* 1903, with the Wright brothers' first controlled, powered, heavier-than-air human flight. *Source:* Mitchell (1998a,b,c).
- **Aviation - passengers:** Civil aviation passenger-KM traveled on scheduled services by companies registered in the country concerned per capita. *Invention date:* 1903, see 'Aviation – cargo'. *Source:* Mitchell (1998a,b,c).
- **Commercial vehicles:** Number of commercial vehicles, including trucks, buses and taxis (excluding tractors), in use per capita. *Invention date:* 1885, when Karl Benz built the world's first practical automobile to be powered by an internal-combustion engine. *Source:* World Bank (2007) and Mitchell (1998a,b,c).
- **Passenger cars:** Number of passenger cars (excluding tractors and similar vehicles) in use per capita. *Invention date:* 1885, see 'Commercial vehicles'. *Source:* World Bank (2007) and Mitchell (1998a,b,c).

### Agricultural technologies

- **Tractors:** Number of wheel and crawler tractors (excluding garden tractors) used per capita. *Invention date:* 1894, when Paterson patented his gas-traction engine. *Source:* FAOSTAT.

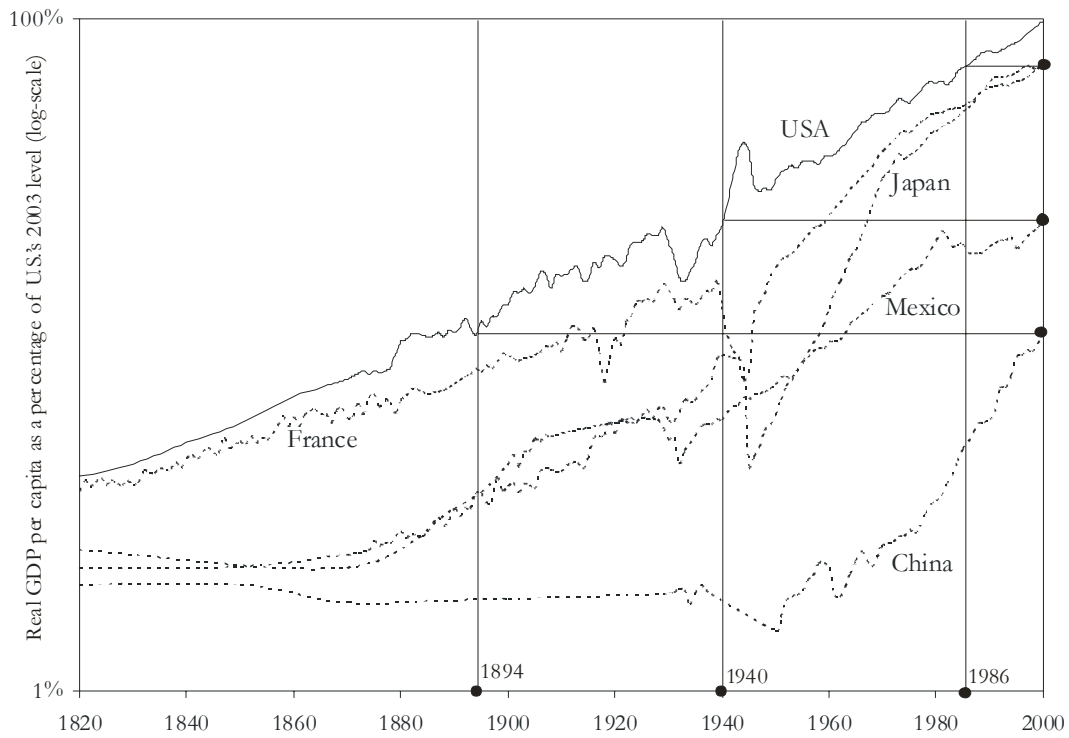


Figure 1. Real GDP per capita lags, examples for 2000

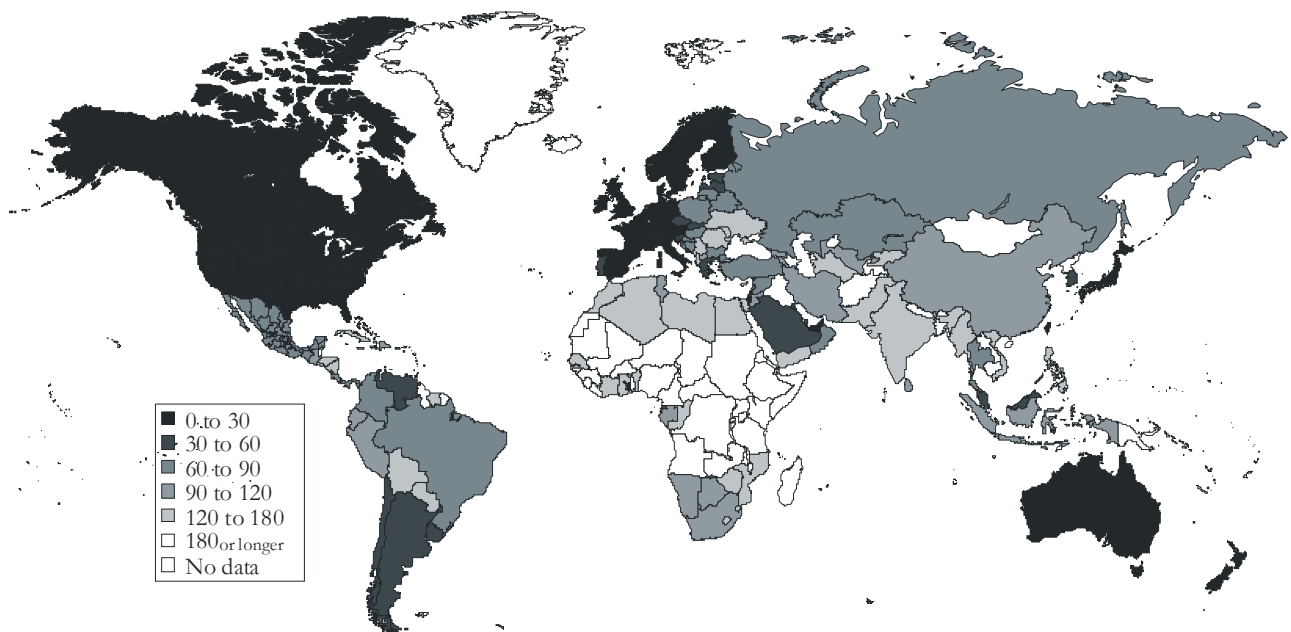
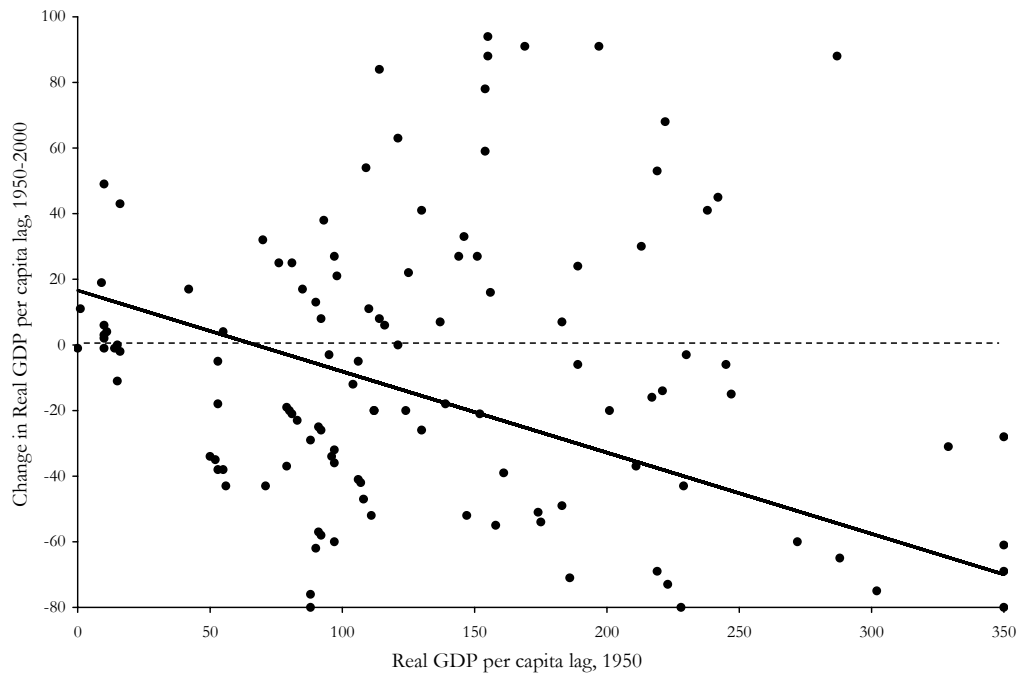
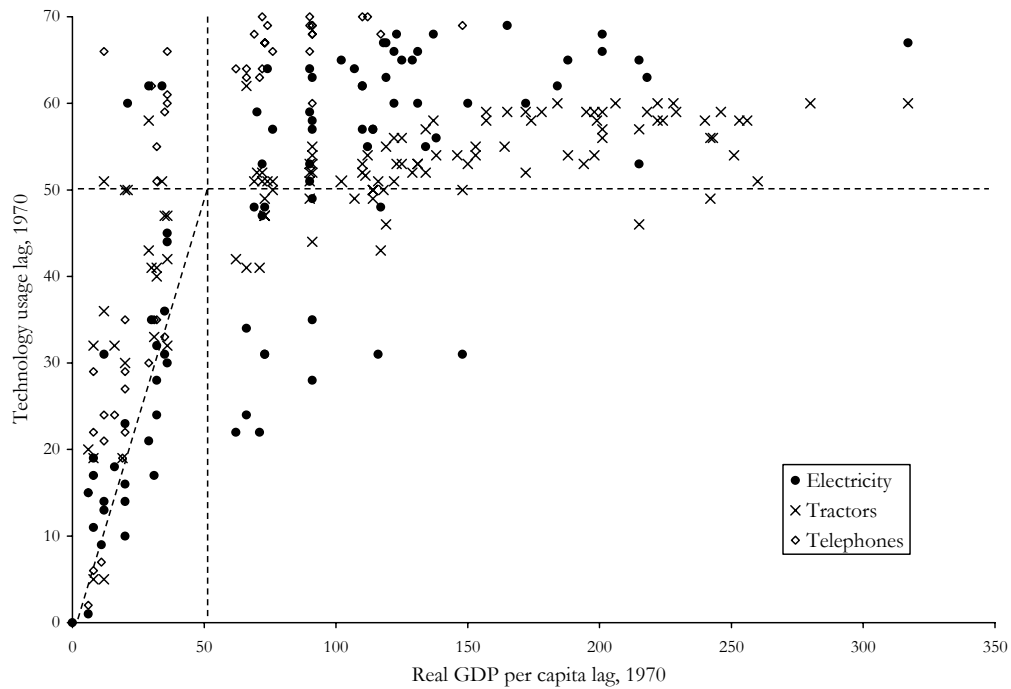


Figure 2. Real GDP per capita lags, 2000

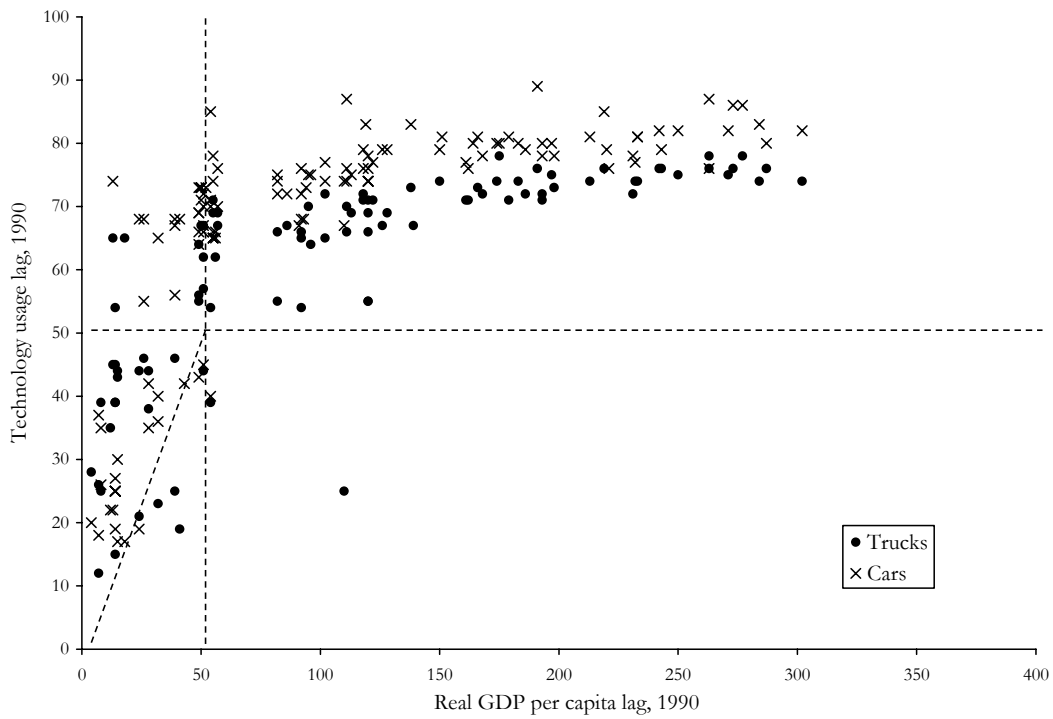


**Figure 3.** Change in real GDP per capita lags between 1950 and 2000

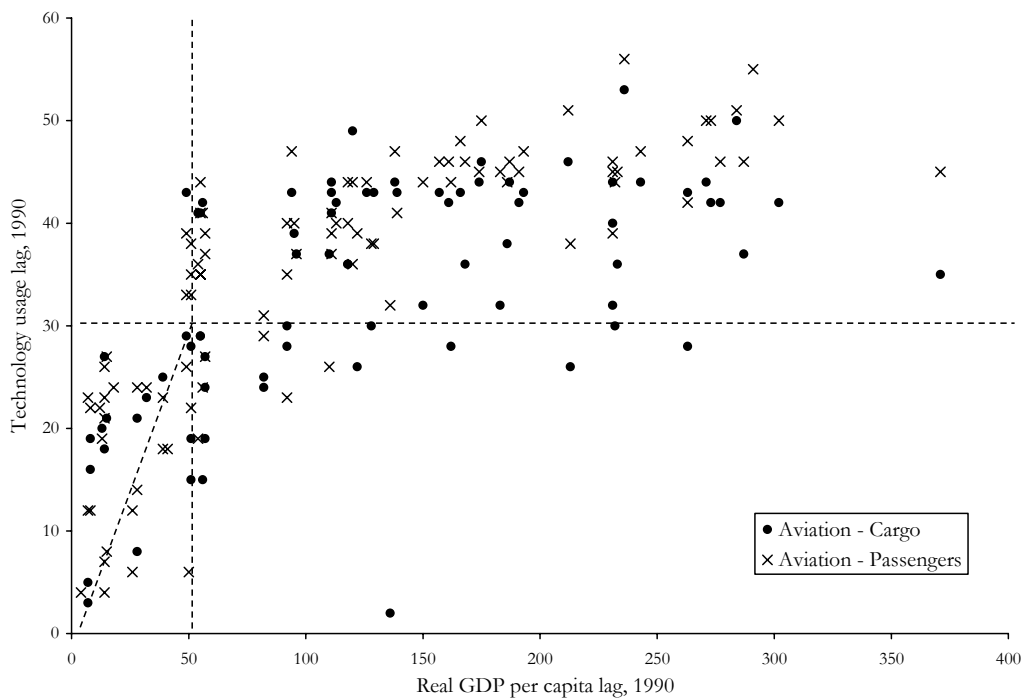


**Figure 4.** Real GDP per capita lags in 1970 versus lags in electricity, tractors, and telephone usage

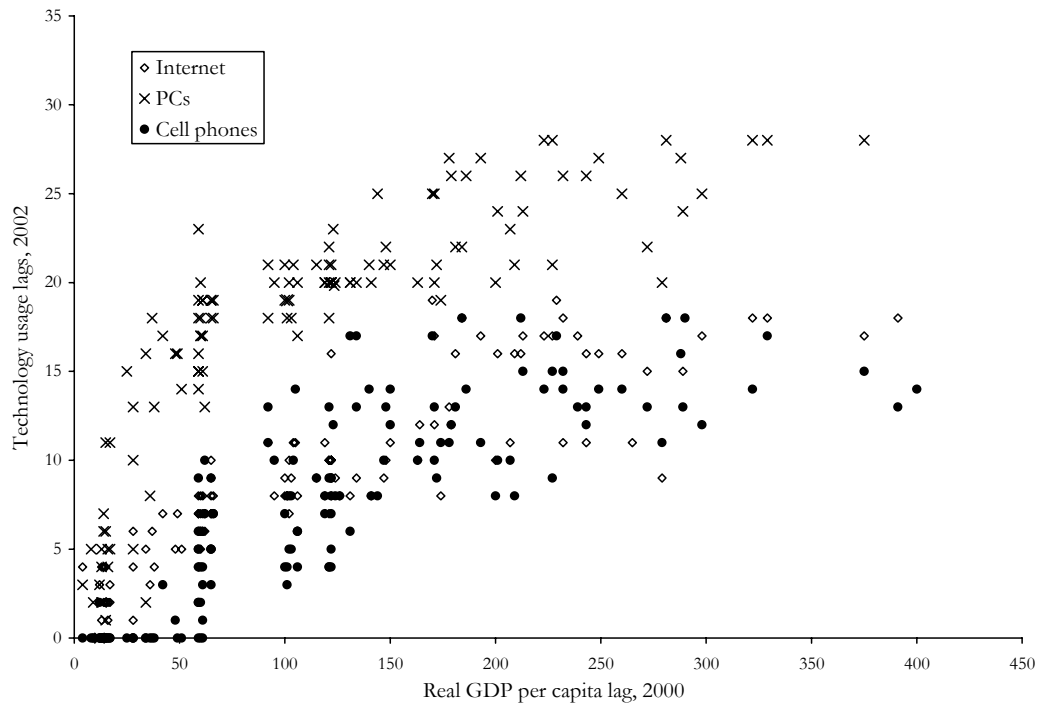




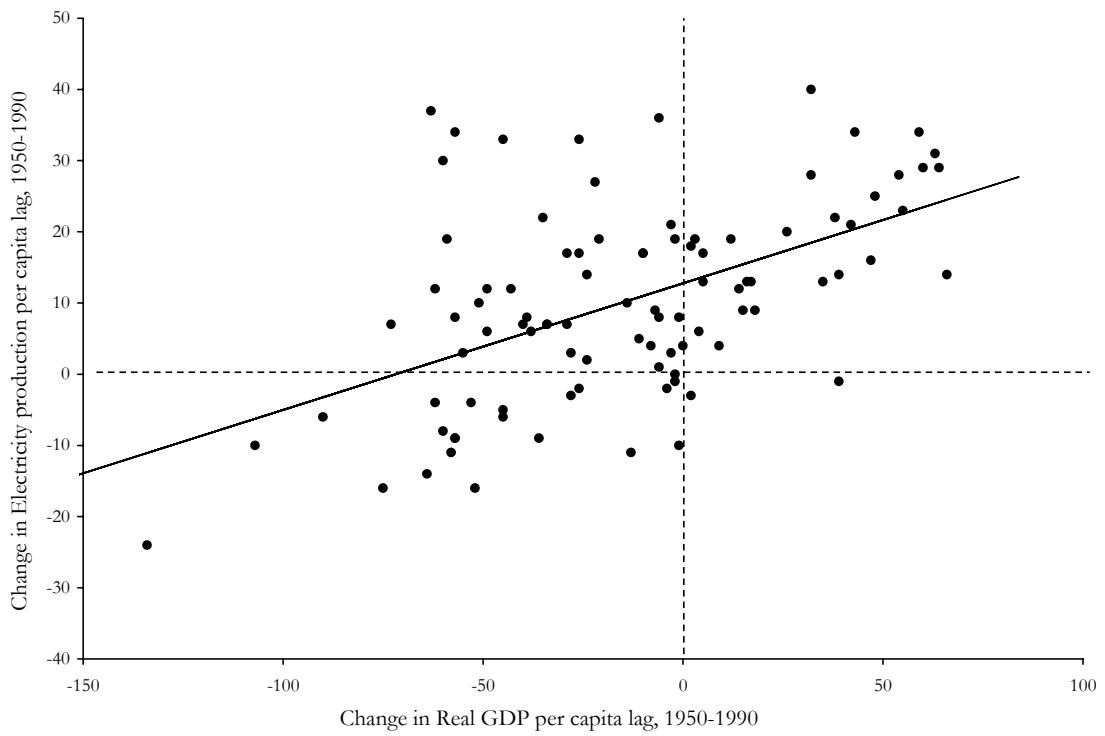
**Figure 5.** Real GDP per capita lags in 1990 versus lags in road transportation



**Figure 6.** Real GDP per capita lags in 1990 versus lags in aviation transportation



**Figure 7.** Real GDP per capita lags in 2000 versus lags in internet, PC, and cell phone usage



**Figure 8.** Change in real GDP lags versus change in electricity production lags

**Table 1.** Summary statistics of technology usage lags for all technologies in particular years.

|            |                       | Correlations and joint sample sizes |             |      |        |         |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|------------|-----------------------|-------------------------------------|-------------|------|--------|---------|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Technology | invention date        | year                                | sample size | mean | median | st.dev. | IQR | 1   | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   | 13   | 14   | 15   | 16   |      |
| 1          | Real GDP              | 1950                                | 138         | 149  | 128    | 93      | 128 |     | 0.93 | 0.82 | 0.75 | 0.77 | 0.75 | 0.75 | 0.77 | 0.71 | 0.71 | 0.75 | 0.61 | 0.70 | 0.63 | 0.71 | 0.63 |      |
| 2          | Real GDP              | 1970                                | 138         | 118  | 114    | 79      | 114 | 138 |      | 0.90 | 0.82 | 0.78 | 0.83 | 0.86 | 0.82 | 0.77 | 0.79 | 0.80 | 0.65 | 0.76 | 0.75 | 0.76 | 0.66 |      |
| 3          | Real GDP              | 1990                                | 164         | 113  | 94     | 82      | 119 | 138 | 138  |      | 0.94 | 0.74 | 0.80 | 0.89 | 0.86 | 0.80 | 0.81 | 0.75 | 0.66 | 0.77 | 0.73 | 0.68 | 0.61 |      |
| 4          | Real GDP              | 2000                                | 164         | 122  | 105    | 89      | 119 | 138 | 138  | 164  |      | 0.69 | 0.75 | 0.83 | 0.87 | 0.80 | 0.82 | 0.70 | 0.65 | 0.75 | 0.68 | 0.65 | 0.58 |      |
| 5          | Electricity           | 1882                                | 1950        | 99   | 46     | 48      | 20  | 29  | 96   | 96   | 97   | 97   |      | 0.94 | 0.89 | 0.81 | 0.82 | 0.72 | 0.90 | 0.66 | 0.75 | 0.80 | 0.88 | 0.81 |
| 6          | Electricity           | 1882                                | 1970        | 124  | 52     | 59      | 25  | 37  | 119  | 119  | 121  | 121  | 99   |      | 0.94 | 0.84 | 0.85 | 0.80 | 0.89 | 0.67 | 0.77 | 0.79 | 0.87 | 0.77 |
| 7          | Electricity           | 1882                                | 1990        | 127  | 58     | 57      | 28  | 46  | 120  | 120  | 126  | 126  | 97   | 121  |      | 0.86 | 0.86 | 0.82 | 0.85 | 0.68 | 0.80 | 0.82 | 0.80 | 0.70 |
| 8          | Internet              | 1983                                | 2002        | 123  | 9      | 8       | 5   | 6   | 101  | 101  | 120  | 120  | 81   | 99   | 103  |      | 0.89 | 0.86 | 0.81 | 0.74 | 0.81 | 0.74 | 0.78 | 0.69 |
| 9          | PCs                   | 1973                                | 2002        | 127  | 18     | 20      | 7   | 6   | 108  | 108  | 124  | 124  | 86   | 107  | 111  | 110  |      | 0.80 | 0.89 | 0.76 | 0.84 | 0.75 | 0.83 | 0.74 |
| 10         | Cell phones           | 1973                                | 2002        | 145  | 8      | 8       | 6   | 11  | 118  | 118  | 142  | 142  | 93   | 116  | 120  | 122  | 127  |      | 0.76 | 0.77 | 0.79 | 0.69 | 0.72 | 0.58 |
| 11         | Telephones            | 1876                                | 1970        | 108  | 63     | 70      | 23  | 15  | 104  | 104  | 106  | 106  | 90   | 106  | 105  | 90   | 95   | 102  |      | 0.70 | 0.79 | 0.83 | 0.93 | 0.84 |
| 12         | Aviation - Cargo      | 1903                                | 1990        | 96   | 27     | 30      | 16  | 23  | 92   | 92   | 95   | 95   | 76   | 93   | 95   | 79   | 88   | 92   | 83   |      | 0.89 | 0.68 | 0.69 | 0.51 |
| 13         | Aviation - Passengers | 1903                                | 1990        | 102  | 34     | 38      | 14  | 21  | 98   | 98   | 101  | 101  | 81   | 99   | 101  | 83   | 92   | 97   | 88   | 96   |      | 0.83 | 0.75 | 0.60 |
| 14         | Trucks                | 1885                                | 1990        | 98   | 59     | 67      | 18  | 26  | 97   | 97   | 98   | 98   | 78   | 96   | 96   | 81   | 84   | 94   | 86   | 78   | 83   |      | 0.82 | 0.66 |
| 15         | Cars                  | 1885                                | 1990        | 127  | 66     | 74      | 20  | 14  | 106  | 106  | 127  | 127  | 81   | 100  | 105  | 102  | 103  | 119  | 92   | 81   | 86   | 97   |      | 0.84 |
| 16         | Tractors              | 1894                                | 1970        | 130  | 47     | 52      | 16  | 11  | 124  | 124  | 128  | 128  | 97   | 121  | 123  | 105  | 113  | 123  | 105  | 95   | 101  | 96   | 107  |      |

Note: 'st.dev.' is standard deviation. 'IQR' is the interquartile range. In the correlations and joint samples sizes part, the numbers above the diagonal are the correlations and the numbers below the diagonal are the sample size on which the correlations are based