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## ABSTRACT

We present evidence on the differences in the intensity with which ten technologies are used in 185 countries. To measure differences in technology use, we determine how long 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) many countries trail the U.S. in technology usage by several decades or more; (ii) usage lags are highly correlated with disparities in per-capita income; and (iii) usage lags are highly correlated across technologies.

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## *1. Introduction*

The United States is widely considered the global technological leader. Most economists would point to the U.S. status as the worldwide leader in output per person[1] as corroborating evidence for this claim. That is, it is widely believed that the high level of real GDP per capita is, in large part, the result of the U.S. relying more intensively on modern technologies for its production processes. To go beyond speculation, however, it is necessary to measure technology directly. The use of such a measure is also essential to any investigation of the determinants of cross-country variation in the intensity of use of current technologies.

Measuring technology presents various challenges. First, technology measures must cover individual narrowly defined technologies. Second, if one wants to be able to draw implications about a country's overall level of technology, the technology measures at the micro level must be either unit free or must have the same units to allow for aggregation. Third, one must select an appropriate scaling factor that controls for the size of the country's economy.

In this paper, we present a novel approach to measuring technology. This approach extends previous work presented in Comin and Hobijn (2004) and Comin, Hobijn, and Rovito (2006) by measuring technology usage in terms of the time lags with respect to the U.S. In particular, we measure how long ago the United States had a similar intensity of technology usage as the country that we consider. The unit of this technology distance measure is years, making it comparable across technologies. In addition, similar measures can be constructed for other non-technology variables, including real GDP per capita.

[1] Measured as real gross domestic product (GDP) per capita. A country's GDP is defined as the market value of all final goods and services produced within a country in a given period of time.

Our analysis uncovers three facts: (*i*) many countries trail the U.S. in technology usage by several decades or more; (*ii*) usage lags are highly correlated with disparities in per-capita income; and (*iii*) usage lags are highly correlated across technologies.

In many respects, the evidence presented here complements that presented in Comin and Hobijn (2004) and Comin, Hobijn, and Rovito (2006).[2 3] As in our previous work, the facts that we present here are mainly of a descriptive nature. In this sense, our main aim is to provide a starting point for further analysis rather than provide the detailed analysis and final conclusions themselves.

## *2. The concept of time lags*

Instead of formally defining the concept of time lags, it is easier to illustrate it with an 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. With this figure we can answer the following question: how many years before the year 2000 did the United States have the real GDP per capita level that China had in 2000?

Looking at Figure 1, we can see that the U.S. passed the level of GDP per capita that China had in 2000 in 1894, 106 years before 2000. Moreover, comparing China to the other countries pictured, one can see that in 2000 the U.S. led Mexico by 60 years and France and Japan by 14.

We consider time lags of this sort in this paper.[5] Looking at these time lags has several advantages. First, they are independent of the units of measurement of the variables examined. This flexibility is

[2] Comin and Hobijn (2004) only covers data from 23 countries rather than the 185 countries covered here. The analysis in Comin, Hobijn, and Rovito (2006) does not include time lags.

[3] The Federal Reserve Bank of Dallas (1996) contains a useful and interesting description of the historical diffusion patterns of consumer technologies in the United States.

[5] Jovanovic (2006) considers this type of time lags in a theoretical model of endogenous growth and technology adoption.

important when one aims to consider evidence on a broad range of technologies across countries, as we do here.

Second, the calculation of these lags does not require a long time series for the country that is compared with the U.S. It only requires a long time series for the U.S.

Our time series for the U.S., while typically long, may not go back far enough, however, which brings us to a limitation of this method; the time-lag measure can be either left or right censored. To see a right-censored case, it is useful to revisit Figure 1. The level of real GDP per capita in China in 1982 was equal to the real GDP per capita in the U.S. in 1820. Thus, if we would like to calculate a real GDP lag for any year before 1982, say 1970, then we can only provide a lower bound for this time lag. That is, we can only indicate that China's real GDP lag with the U.S. in 1970 was *more* than 150 years. This case is not an anomaly. As we will see throughout our analysis, many countries have standards of living and levels of technology usage that are lower than those ever recorded in the United States.[6]

Though it is possible to analyze censored data by making assumptions about its distribution, our exploration in this paper relies mostly on graphical analysis.

## *3. Real GDP per capita lags*

Differences in standards of living across the world are staggering. For example, U.S. real GDP per capita in 2000 was almost 19 times higher than that of 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 into years behind the United States. Figure 2 shows the time lags in real GDP per capita for almost all countries in the world in 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, which is the start of the historical time series on U.S. real GDP levels.

It is well documented, for example by Baumol (1986) and Barro and Sala-i-Martin (1992), that countries that start off at relatively low per-capita GDP levels tend to grow faster than countries that are richer at the onset. We find a similar pattern of catch-up in our time-lag measurment. Figure 3 shows the change in the per-capita GDP lags between 1950 and 2000 plotted against the initial lag in 1950.[7] 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 (more 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 from 1950 to 2000, Ireland's GDP per capita increased by the same amount as the U.S.'s GDP per capita over the period from 1894 through 1987. The country with the biggest leap forward from 1950 to 2000 is Taiwan, which saw a reduction in its GDP per capita lag of more than 106 years.

Not all countries saw their GDP lags decrease over the period from 1950 to 2000. This divergence is indicative of the polarization in real GDP per capita documented by Quah (1997). Many of the poorer countries in the sample are right censored in both 1950 and 2000, while others, like Zimbabwe, Mozambique, and Ecuador, saw their distance from the U.S. increase by two decades or more.

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[6] The left-censored case, which happens infrequently in the data we consider, is the case in which the U.S. lags instead of leads. In this case, the time lag is negative, indicating that a country's level of technology usage has not (yet) been observed in the U.S.

[7] The maximum initial lag in per-capita GDP in 1950 is 130 because the first observation for U.S. GDP in our data is from 1820.

An extensive literature has tried to locate the main sources of the cross-country differences in per-capita GDP levels. This literature typically assumes that GDP, or output, 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 are due to differences in TFP, rather than to differences in the capital per worker.

The cause of cross-country disparities in TFP levels is a controversial topic in economics.[8] One view proposes that cross-country variation in TFP stems from high TFP countries' use of more of the advanced technologies available. An alternative view is that factors other than technology account for a majority of cross-country TFP differences and that variation in the usage of modern technology may be just a reflection of the variation in per-capita income. In this short paper we do not attempt to shed light on this debate. However, Comin and Hobijn (2005) have used micro evidence to document that the technologies analyzed here seem to have improved the productivity of labor and standards of living enormously. Hence, finding a large cross-country variation in the technology usage lags would suggest that a significant part of cross-country variation in TFP is generated through the differences in the usage of advanced technologies.

In the following section, we consider the degree to which the cross-country time lags in per-capita income, and thus TFP, mirror the lags in the usage intensity of various consumption and production technologies.

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[8] 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.

[10] The number in parentheses in the legend of these figures represents the upper bound on the usage lag, i.e. the level above which values are censored.

# *4. Technology usage lags*

The ten consumption and production technologies that we consider can be classified into four broad categories: (*i*) electricity, (*ii*) information technologies, (*iii*) communication technologies, and (*iv*) transportation technologies. Appendix A contains a description of the technologies that we use, our data sources, units of measurement, and the samples for which we have data. As for real GDP, we measure the intensity of usage of these technologies in per-capita terms.

Figures 4, 5, and 6 depict the technology usage lags of nine out of the ten technologies in our sample versus those of real GDP per capita.[10] Figure 4 compares the electricity, truck, and car usage lags in 1970 with the 1970 real GDP per capita lags. Figure 5 does the same for the 1970 television and aviation usage lags. Figure 6 shows the 2000 cell phone usage lags and the 2002 PC and internet usage lags plotted against the 2000 real GDP per capita lags.[11] The dashed line in each of these figures represents the 45-degree line, on which technology usage lags are identical to real GDP per capita lags.

The first conclusion from these figures is the following.

*Conclusion 1: Many countries trail the U.S. in technology usage by several decades or more.*

As can be seen from Figure 4, for countries with real GDP per capita lags smaller than 40 years in 1970, technology usage lags in electricity and road transportation were generally higher than GDP lags. Moreover, countries with real GDP per capita levels in 1970 comparable to those in the pre-WWI U.S. also seem to have pre-WWI levels of technology usage in electricity and road transportation.

To put this in perspective, consider that the countries that lagged the U.S. by more than 50 years in electricity production in 1970 are countries in which electricity production was not enough to light one 60-watt light bulb per person continuously. For road transportation, we similarly find that 32 out of the

[11] In order to keep them readable, we have not included telephones per capita in these figures. The observed qualitative pattern for telephones per capita mirrors that of the other technologies that we consider.

112 countries for which we have data in 1970 had levels of car usage comparable to or lower than those in the U.S. in 1908, when Henry Ford sold his first Model T, which is generally considered the car that "put America on wheels."

The results for aviation and televisions in Figure 5 are similar, though the usage lags are smaller because these technologies were invented later than the ones in Figure 4.

Figure 6 focuses on three technologies developed more recently, PCs, cell phones, and the internet. For PCs we find that, in 2000, most countries are using PCs at a level that predates the U.S. 1990 level. 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. The internet and cell phones, meanwhile, provide examples of technologies for which the U.S. is not the leader in usage intensity. In 2002, Australia, Canada, Denmark, Singapore, and Sweden all had more internet users per capita than the U.S. At the same time, though the U.S. is not the leader, 51 out of the 123 countries for which we have data had internet usage levels in 2002 that had not been observed in the U.S. since the introduction of web browsers in 1993. The U.S. trails even more countries in cell phone usage than it does in internet usage. In 2000, cell phone usage in 28 out of the 145 countries in our sample exceeded that in the U.S. These countries include, among others, almost all of Western Europe, Australia, New Zealand, Japan, Singapore, and South Korea, as well as the Czech Republic and Slovenia.

In addition to the levels of the usage lags, we can also study the relationship between technology usage and per-capita GDP time lags.

*Conclusion 2: Technology usage lags, for all technologies in our sample,*

*are highly correlated with real GDP per capita lags*

This property is evident from Figures 4, 5, and 6. For all the technologies depicted in these figures, the average technology usage lag is increasing in the real GDP lag. This observation holds even though the figures under-represent this correlation for the technologies that contain a large number of right-censored observations.[12]

This observation is consistent with a positive correlation between levels of GDP per capita and technology usage documented in Comin and Hobijn (2004)[13] and Comin, Hobijn, and Rovito (2006). It is also in line with the evidence in Caselli and Coleman (2001) that shows that, among a broad set of potential explanatory variables, real GDP per capita has the most explanatory power with respect to cross-country differences in PC usage.

For electricity we not only find a high correlation between the levels of usage lags and those of GDP per capita, but also between the changes of the technology and income lags. Figure 7 illustrates this correlation. This figure has only one observation in the lower right-hand quadrant, indicating that all (but one) countries that were catching up with the United States in electricity production in the second half of the twentieth century also reduced their per-capita income lags. The strength of this correlation points to the important role that electrification, as a general purpose technology, played in economic development in the last century.

It is often argued that the computer is the first general purpose technology since electricity.[14] It is not surprising, then, that countries that lagged the U.S. the most in electricity in the middle of the 20$^{th}$ century also tend to be the countries that lagged the U.S. the most in PCs at the end of the 20$^{th}$ century. Figure 8 illustrates this point by plotting the 2002 usage lag in PCs against the 1950 usage lag of electricity.[15]

This finding also holds more generally, leading us to our final observation.

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[12] This effect works in the other direction for cell phones and, to a much lesser extent, internet usage due to the presence of left-censored observations.

[13] This correlation is also robust over time, as shown for 23 industrialized countries for the pre-WWII period.

[14] David (1990) puts this claim in a historical perspective.

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

This positive correlation is apparent for the technologies that are jointly plotted against GDP in Figures 4, 5, and 6. However, it is also useful to see technologies plotted against one another directly; in particular, it may be useful to compare similar technologies. For that reason, we examine the relationship between telephone usage lags in 1960 and cell phone usage lags in 2000 in Figure 9. As can be seen from the figure, most of the countries that were ahead of the U.S. in cell phone usage in 2000 were countries that were less than 50 years behind the U.S. in phone usage in 1960.

One interesting conclusion from Figures 8 and 9 is that the positive correlation in usage lags does not only hold contemporaneously, but also holds for lags for different technologies measured decades apart. Skinner and Staiger (2005) document similar correlations in cross-state adoption patterns of several, seemingly unrelated technologies over time for the U.S.

Some interesting dynamics that deserve further investigation are apparent in the technology usage lags. When we consider the position of the non-censored technology usage lag observations relative to the 45-degree line in Figures 4, 5, and 6, we find that many developing countries seem to 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, including mobile communications and information technology, than they did in older technologies, such as electricity or cars. It is, however, difficult to determine if this observation is robust or if it is merely the result of right censoring in our usage lag measures.

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[15] The four outlying observations on the lower right side of the figure are Ireland (36,5), Hong Kong (44,5), Singapore (42,0), and South Korea (48,2).

## *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 telephones, lags the technology usage level in the U.S. by several decades. These usage lags are highly correlated with the level of economic development of each country. Moreover, they are correlated across technologies. This suggests that the existence of important factors that jointly drive economic development and the incentives to adopt and use the various technologies in our sample. The identification of these determinants is the subject of our ongoing research agenda.

Many developing countries seem to 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, including mobile communications and information technology, than in older technologies. However, a more complete analysis must be undertaken to determine if this observation holds up when other measurements and other technologies are considered.

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## *A. Data: sources and definitions*

***Sources:*** Real GDP per capita data come from Maddison (2007); all other data are taken from the Cross-Country Historical Adoption of Technologies (CHAT) dataset, described in Comin, Hobijn, and Rovito (2006).

***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. In parentheses is the period covered by the U.S. time series that we use as our benchmark.

**Standard of living**

- **Real GDP per capita:** Gross domestic product measured in 1990 International Geary-Khamis dollars. (1820-2003)

**Electricity**

- **Electricity:** MWh of electricity produced per capita. (1902-1993)

**Information technologies (IT)**

- **Internet users:** Number of internet users per capita (1990-2002)
- **Personal computers:** Number of personal computers per capita (1981-2002)

**Communication technologies (CT)**

- **Cell phones:** Number of cell phones per capita (1984-2002)

- **Telephones:** Number of mainline telephones per capita (1880-1980)
- **Televisions:** Number of televisions per capita (1946-2001)

**Transportation technologies**

- **Aviation - cargo:** Number of ton-kilometers of cargo on airplanes per capita (1928-1991)
- **Aviation - passengers:** Number of passenger-kilometers on airplanes per capita (1930-1993)
- **Commercial vehicles:** Number of commercial vehicles/trucks per capita (1904-1993)
- **Passenger cars:** Number of passenger cars per capita (1900-1993)

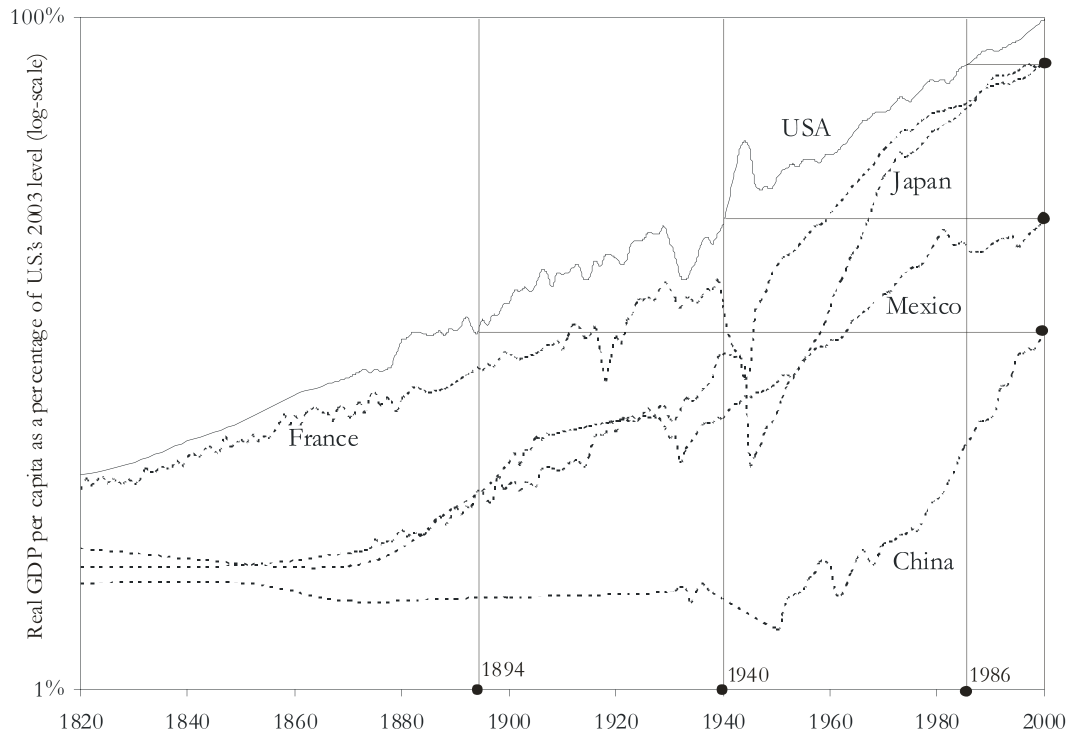


**Figure 1.** Real GDP per capita lags, example countries for 2000

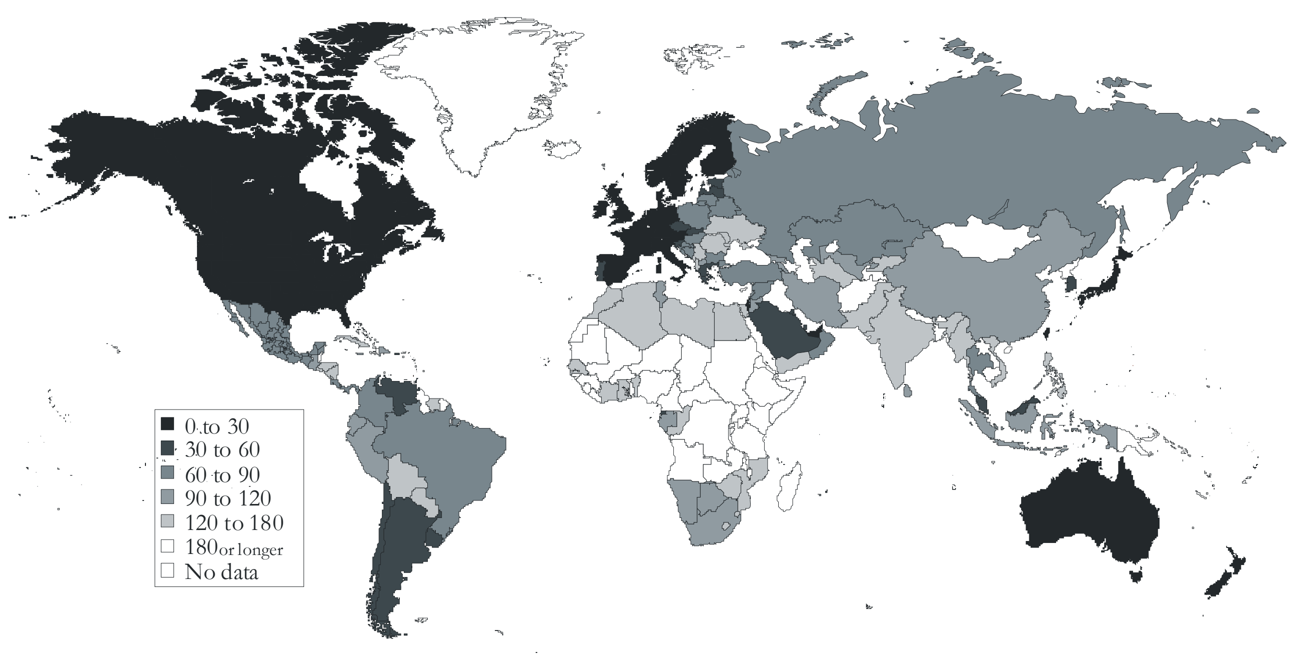


**Figure 2.** Real GDP per capita lags, 2000

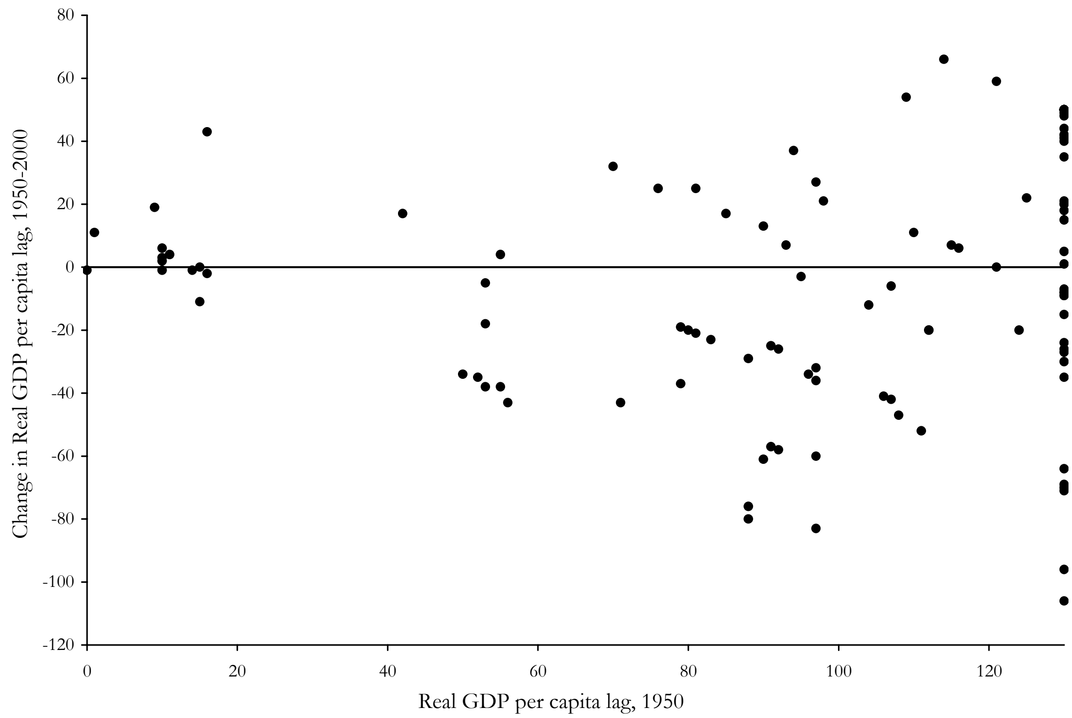


**Figure 3.** Change in real GDP per capita lags between 1950 and 2000

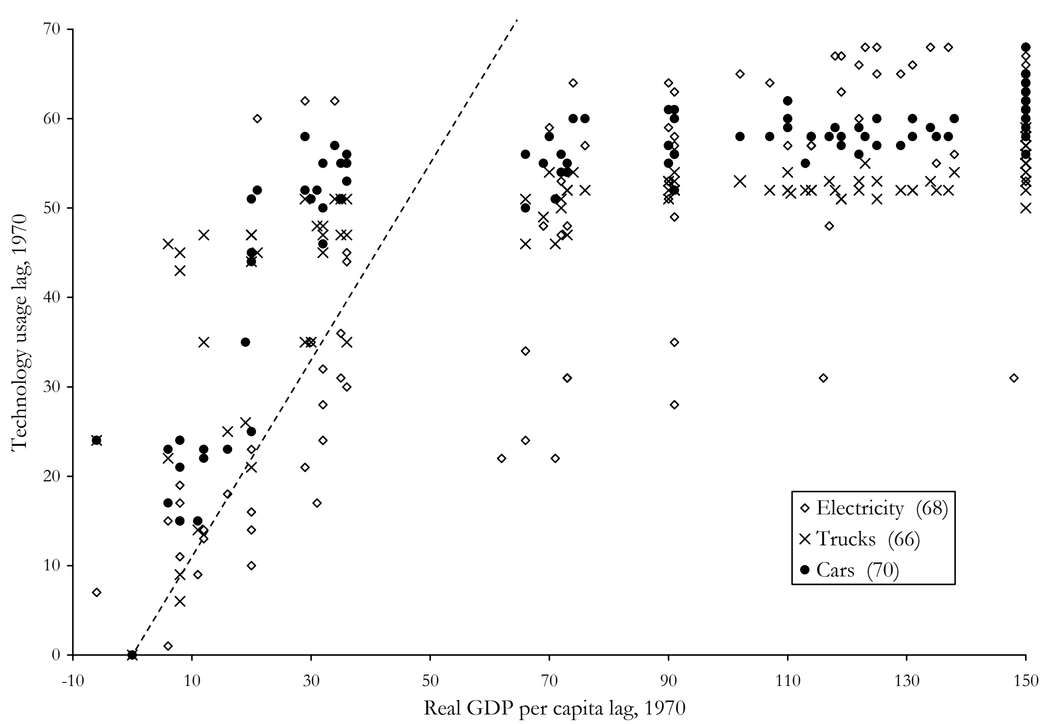


**Figure 4.** Real GDP per capita lags in 1970 versus lags in electricity, truck, and car usage

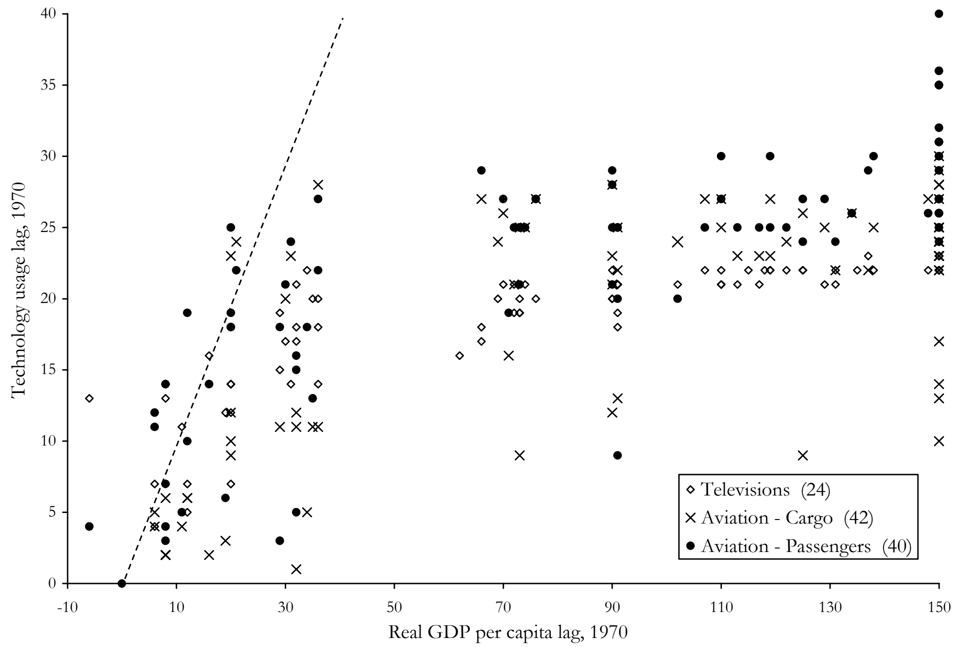


**Figure 5.** Real GDP per capita lags in 1970 versus lags in television and aviation usage

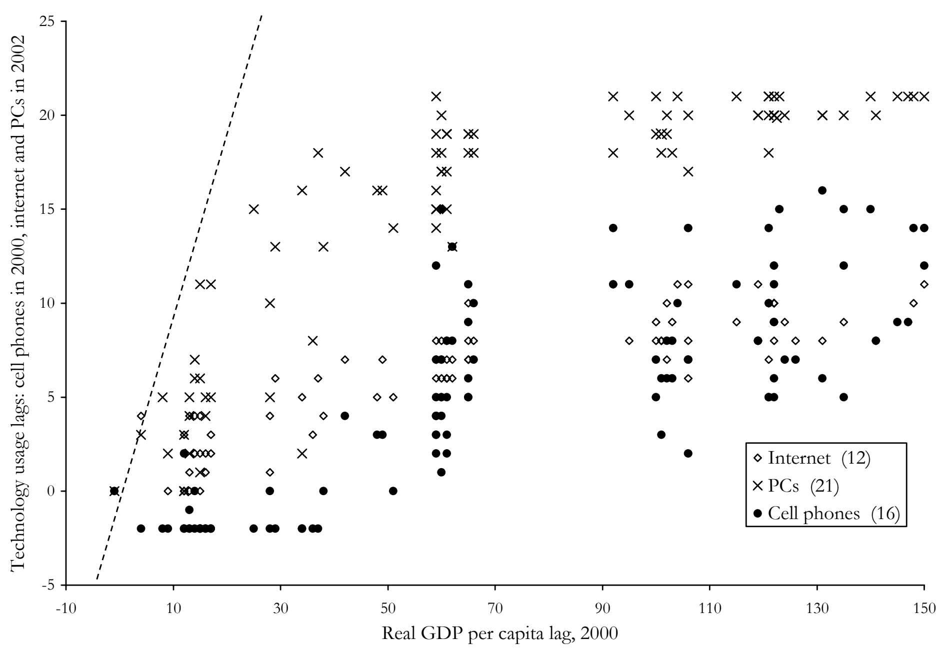


**Figure 6.** Real GDP per capita lags in 2000 versus lags in internet, PC, and cell phone usage

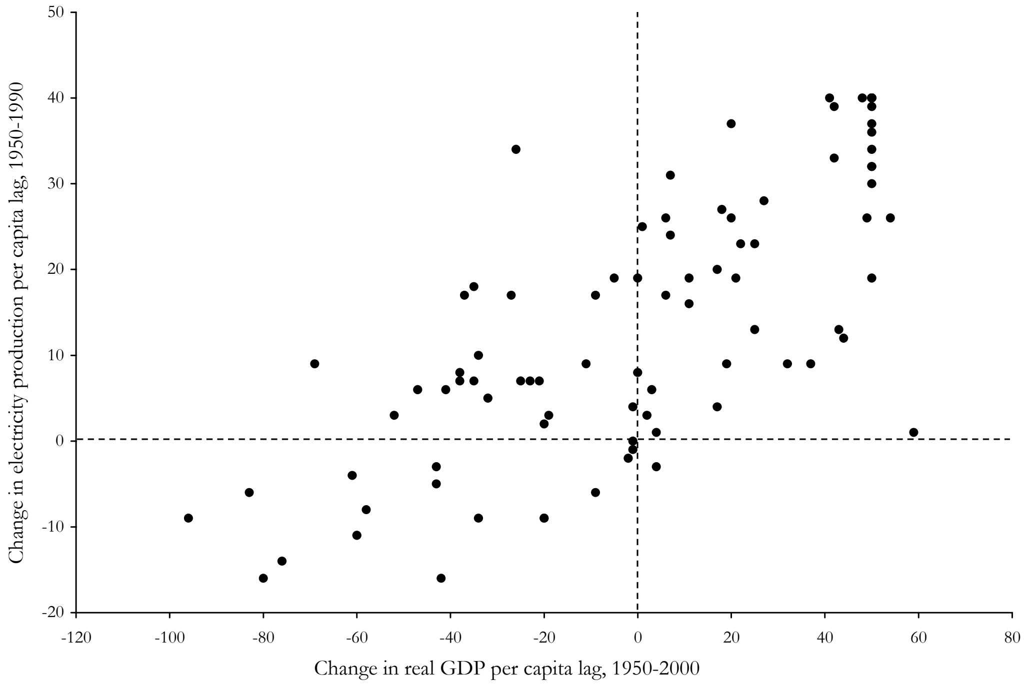


**Figure 7.** Change in real GDP lags versus change in electricity production lags

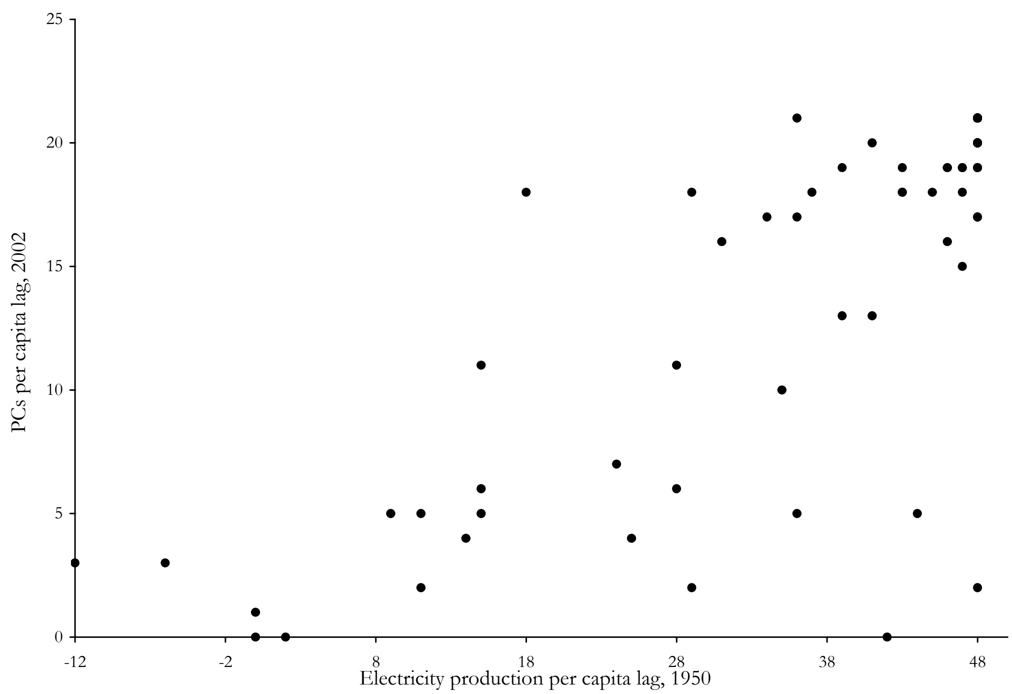


**Figure 8.** Electricity usage lags in 1950 versus PC usage lags in 2002

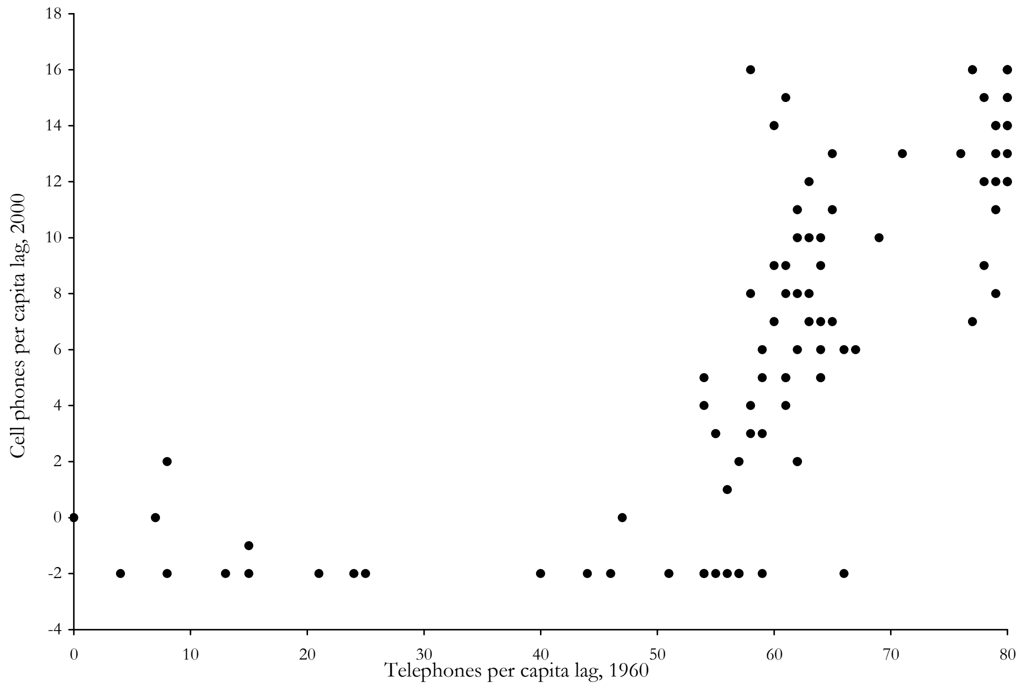


**Figure 9.** Telephone usage lags in 1960 versus cell phone usage lags in 2000