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A new approach to measuring technology with an application to the shape of the diffusion curves

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Abstract This paper documents the sources and measures of the cross-country historical adoption technology (CHAT) data set that covers the diffusion of about 115 technologies in over 150 countries over the last 200 years. We use this comprehensive data set to explore the shape of the diffusion curves. Our main finding is that, once the intensive margin is measured, technologies do not diffuse in a logistic way.

Keywords Technology adoption · Cross-country studies

JEL Classifications O33 · O47 · O57

Technology plays a central role both in macroeconomics and in economic development. Real business cycle theory places technology at the root of economic fluctuations (Kydland and Prescott 1982). Growth theory has long postulated that improvements in technology are the source of long-run growth (Solow 1956; Romer 1990; Aghion and Howitt 1992)

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and that differences in technology are the main determinant of income per capita differences across countries (Klenow and Rodriguez-Clare 1997; Hsieh and Klenow 2007).

To test these and other assertions of macro theory it is important to have direct measures of technology. However, current measures of technology are not completely satisfactory. The Solow residual, the most commonly applied measure of technology, has been criticized because, in addition to technology, it also captures the variation in capacity utilization (Basu 1996), labor hoarding (Burnside et al. 1995), and the inefficiencies of the economy (Weil 2004, chap. 10).

A more direct way of measuring technology involves measuring the share of potential adopters that have adopted a given technology at a point in time (Griliches 1957; Mansfield 1961; Gort and Klepper 1982; Skinner and Staiger 2005). This approach has two drawbacks. First, while this measure captures the extensive margin of technology adoption, it neglects the intensive margin (i.e. how intensively each adopter uses the technology). Second, its computation requires the use of hard-to-obtain micro-level data. As a result, the diffusion of only a limited number of technologies for a limited number of countries can be documented using such measures.

This paper has two goals. First, it describes in detail the coverage and sources of our cross-country historical adoption technology (CHAT) data set that covers the diffusion of about 115 technologies in over 150 countries during the last 200 years across many sectors of economic activity.[1] Since we measure technology directly, our measures are not subject to the type of criticisms raised against the Solow residual. Furthermore, as in Comin and Hobijn (2004), our measures of technology capture both the extensive and the intensive margins of diffusion.

The second goal of this paper is to use this data to explore whether the logistic curve provides a good approximation to the diffusion process once we include the intensive margin in the measure of diffusion. The main finding we present is that the evolution of the level of the technology in the country does not typically follow a logistic pattern once the intensive margin is taken into account.

The rest of the paper is structured as follows. The next section discusses the various conceptual and practical issues of measuring technology and describes the data set. Section 2 explores the shape of diffusion curves for each country-technology pair and shows that S-shaped diffusion is only applicable for a limited set of technologies. Section 3 concludes.

1 Measurement

According to the Merriam-Webster's Collegiate Dictionary, technology is

> *"a manner of accomplishing a task especially using technical processes, methods, or knowledge"*

Next we discuss various conceptual and practical issues that arise when attempting to measure technology levels.

1.1 Conceptual issues

One approach to measuring technology diffusion, used in Griliches (1957) and Mansfield (1961), assumes that the adoption of technologies is a binary decision; producers or

[1] The data set can be freely downloaded from the NBER web page.

consumers can either adopt a technology or not adopt it. The ratio of the number of users of the technology to the number of potential users measures this extensive margin.

For some technologies, however, the intensive margin may be as relevant as the extensive. For example, in transportation technologies, the improvement in productivity is proportional to the frequency of use, not to whether the technology is used at all. In addition, for some technologies, such as computers and cars, it is not unreasonable to think that, in the long run, each potential adopter might adopt more than one unit of the good. Similarly, technological change in cotton spinning has been directed toward increasing the number of spindles that each worker can operate simultaneously. Thus, we consider it necessary to incorporate the intensive margin into measurement of technology diffusion. By doing that, we may be studying a different phenomenon than what the diffusion literature has previously explored, and some new terminology might be necessary. Conversely, one may think that technologies also diffuse along the intensive margin and employing the traditional terminology to refer to more comprehensive measures of the adoption of technologies may be appropriate. This latter opinion is our view on the matter, and, in the rest of the paper, we continue to talk about technology diffusion as encompassing both the intensive and the extensive margins.

To capture the intensive margin, we use measures of technology for which the numerator depends on the intensity with which each producer or consumer adopts the technology. For example, the diffusion of credit and debit cards is measured by the number of credit and debit card transactions per capita or by the number of points of service per capita, instead of by the share of people that has at least one credit card. This latter measure would capture only the extensive margin.

Since technology is often embodied in capital goods, many of our measures correspond to the number of specific capital goods per capita. We measure computers and telephones in this way. Other technologies take the form of new production techniques. In these cases we measure the diffusion of the technology either by the share of output produced with the technique (i.e. share of steel produced with blast oxygen furnaces) or directly by the technique's level of diffusion (i.e. number of credit and debit card transactions or cheques issued, both on a per-capita basis).

An important issue concerns the heterogeneity of units in our measures of technology. We remove units from our measures either by taking logs (i.e. log of number of MRI units per capita) or by looking at shares (i.e. share of farmland that uses high yield varieties).

1.2 The CHAT data set

The cross-country historical adoption of technology (CHAT) data set is an unbalanced panel with information on the diffusion of about 115 technologies in over 150 countries during the last 200 years. Table A1 (in the appendix) describes, for each country, the number of technologies for which we have data that span at least three 5-year periods. The average number of technologies per country is about 34, while the median is 28. Table 1 describes the geographic distribution of the countries in our sample and the distribution of the number of technologies (that span at least three 5-year periods) for countries in each continent. One interesting feature of the data set is that, even in continents that have predominantly low-income countries, such as Africa, the number of technologies in the typical country is fairly large. In this respect, the CHAT data set improves on previous data sets on technology diffusion, including the HCCTAD, which was presented in Comin and Hobijn (2004) and covered the diffusion of 25 technologies in 23 developed economies.

Table 1 Geographic distribution of sample countries and technologies

Region	Mean technologies per country	Median technologies per country	Standard deviation of technologies per country	Number of countries
Total	34.2	28.0	20.37	159
Africa	24.9	26.0	9.00	48
Asia	28.9	26.5	12.51	44
Europe	49.3	41.5	28.23	38
North America	34.0	27.5	22.64	12
Oceania	43.3	44.0	21.09	4
South America	40.0	44.0	20.94	13

In addition to covering the countries in the world evenly, a comprehensive data set on technology diffusion must represent the various sectors in the economy. Table 2 describes the number of technologies covered by the CHAT data set in each of eight major sectors in which the technologies are primarily used. These sectors are agriculture, finance, health, steel, telecommunications, textiles, tourism, and transportation. Three of our technologies, namely electricity production, the number of computers, and the number of internet users, are used across the economy. They represent general purpose technologies and thus defy categorization by sector; we place them in a separate group.

The first observation from Table 2 is that the data set covers eight sectors that represent a significant portion of GDP in most of the countries. In the U.S., for example, the sectors covered by the data set represented approximately 55 added in the private sector in 2000.

In addition, the data set covers a substantial number of technologies in each of the sectors. These range from 2 technologies in tourism to 49 in health. Along this dimension, the CHAT data set also constitutes a substantial improvement over the HCCTAD, which does not contain information on the technologies in agriculture, finance, health, and tourism and has only 25 technologies, instead of about 115.

Our technology data comes from multiples sources. Agricultural variables come from FAOSTAT and from Evenson and Gollin (2003). Data on financial technologies comes from the European Central Bank, the Bank for International Settlements, and EMEAP (2002). Electricity production comes from Mitchell (1998a, b, c) and the World Bank, while the number of internet users and computers comes from the World Bank. All of the health technologies come from the OECD, except the immunization rates which

Table 2 Technology sector coverage

	Technologies per sector
Agriculture	8
Finance	5
General purpose	3
Health	49
Steel	14
Telecommunications	8
Textiles	6
Tourism	2
Transportation	21

come from the World Bank. Data on steel comes from the International Iron and Steel Institute. Data on telecommunication technologies comes from the World Bank, Mitchell (1998a, b, c) and Banks (2004). Data on textile technologies comes from the International Cotton Association. Data on hotels and visitor beds comes from the World Tourism Organization. Finally, the transportation technology variables are collected from Mitchell (1998a, b, c).

2 Diffusion curves are not logistic

At least since Griliches (1957), economists have acknowledged the good approximation that S-shaped curves, such as the logistic, provide to the process of technology diffusion as measured by the extensive margin. The logistic curve is defined by

$$Y_t = \frac{\delta_1}{[1 + e^{-(\delta_2+\delta_3 t)}]} \tag{1}$$

where t represents time, in our case measured in years, δ_3 reflects the speed of adoption, δ_2 is a constant of integration that positions the curve on the time scale, and δ_1 is the long-run outcome (the limit of Y_t for t going to infinity).

Several features of this curve are relevant. First of all, it asymptotes to 0 when t goes to minus infinity and to δ_1 when t goes to infinity. Secondly, it is symmetric around the inflection point of $Y_t = 0.5\delta_1$ which occurs at $t = -\delta_2/\delta_3$. Finally, the 1% diffusion point (i.e. the time in which $Y_t = 0.01\delta_1$) is given by $t = (-\ln(0.99) - \delta_2)/\delta_3$. On account of its good fit when the extensive margin of adoption is measured, the logistic has often been used to reduce the process of technology diffusion to the three parameters that define it, namely δ_1, δ_2, and δ_3.

The first question that we investigate is whether this approximation of a country's technology diffusion still provides a reasonable approximation once the measure of technology diffusion incorporates the intensive margin. To answer this question we fit a logistic curve to each of the 5,678 technology-country pairs and explore the implications of the estimates. Specifically, let Y_{ijt} be the level of technology i in country j at time t. The curve we fit is as follows:

$$Y_{ijt} = \delta_{1ij}/[1 + e^{(-\delta_{2ij}-\delta_{3ij}t)}] + \varepsilon_{ijt} \quad \text{where } \varepsilon_{ijt} \sim N\left(0, \sigma_{ij}^2\right) \tag{2}$$

We first find that, for 23% of the technology-country combinations, it is not possible to fit logistic to the diffusion curves, likely because of the data's lack of curvature. When the diffusion line does not have sufficient curvature, the log-likelihood function is flat for many parameter configurations, and it is therefore not possible to determine the parameter configuration that maximizes the log-likelihood function. In these circumstances, we cannot identify the parameters that govern the curvature of the logistic. We take this as an indication that the logistic provides a poor approximation to the diffusion of technology i in country j.

When the estimation converges, the R^2 tends to be very high. In particular, conditional on obtaining an estimate, the R^2 is above 0.90 for 89% of the technology-country pairs.

The R^2 is not a good measure of fit for logistic curves. It is well known that, since both the fitted logistic curves and the data contain trends, the high R^2s reflect the fit of this trend and not of the fluctuations around it. Therefore, for a better sense of the appropriateness of the logistic approximation, we have to go beyond the R^2.

Table 3 Deviations from logistic diffusion

	Number of technology-country pairs	Cumulative failure of logistic
Total country-technology pairs	5,678	
Flatness of likelihood surface	1,291	1,291
Negative estimate of δ_3	454	1,745
Too early predicted adoption	202	1,947
Too late predicted adoption	336	2,283
Growing ceiling	1,098	3,381

In particular, we explore how the data conforms to three properties of the logistic. First, logistic curves increase monotonically from the introduction of the technology to a ceiling. This implies that the estimate of δ_{3ij} should be positive. This is the case for a majority of technology-country pairs, but a substantial number of pairs (920 out of 4,387) have a negative estimate of δ_{3ij}. In some instances, such as open hearth steel production or the number of mule spindles, the negative estimate of δ_{3ij} results from the partial or complete replacement of the technology by a better technology. The replacement of a dominated technology may, of course, be consistent with a logistic diffusion.

In other cases, however, the negative estimate of δ_{3ij} does not result from the replacement of the technology but simply from the fact that the use of technology is growing at a lower rate than the population (i.e. cars in Tanzania). These cases contradict the hypothesis of logistic diffusion.

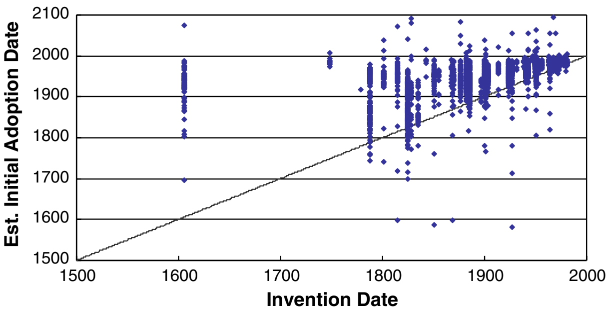
In order to precisely identify cases that violate this property of logistic diffusion, we would have to examine each of the 920 pairs individually. This would involve an, in large part, arbitrary classification of our results. However, we can make a conservative estimate of the number of technology-country pairs for which the negative estimate of δ_{3ij} does not result from the substitution by a superior technology. Since the relative productivity of two competing technologies is likely to be similar across countries, the introduction of a superior technology will likely induce the eventual replacement of the original technology in all countries and will thus produce negative estimates of δ_{3ij} for a majority of countries. Therefore, we can use the fraction of negative estimates of δ_{3ij} to guide our judgments.

For 15 out of 115 technologies in CHAT, at least 50% of the countries have negative estimates for δ_{3ij}. As expected, the technologies include measures such as open hearth and Bessemer steel production and the number of sail ships, hospital beds, and cheques, all of which have been recently dominated by another technology. Meanwhile, the list of technologies that do not have a majority of negative estimates of δ_{3ij} includes a few technologies, such as the number of telegrams sent, that have been dominated in some countries. Using the 50% cutoff as a general guide for selecting non-dominated technologies, we find that 454 of the 920 technology-country pairs with a negative estimate of δ_{3ij} violate one of the assumptions of logistic diffusion by not increasing monotonically to a ceiling (Table 3, row 4).[2]

Next, we explore the predicted initial adoption dates to detect further issues with the logistic approach. To determine predicted initial adoption dates, we use our estimates of Eq. 2 to find the predicted time at which 1% of the estimated ceiling adoption level was reached.

[2] From this point forward, we consider only technologies with positive curvature parameters.

Fig. 1 Predicted initial adoption under logistic versus invention dates for technology-country pairs



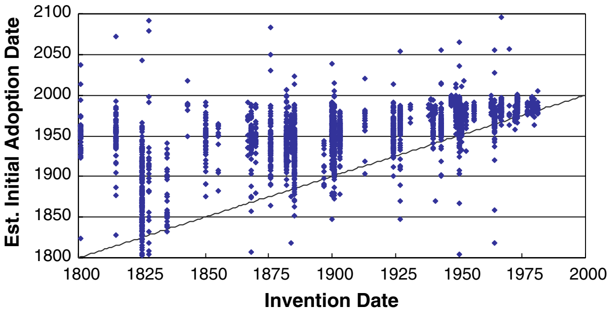


Fig. 2 Predicted initial adoption under logistic versus invention dates (1800–2000)

Then, we compare these to each technology's invention date. Figures 1 and 2 plot these predicted adoption dates and actual invention dates for every technology-country pair.[3] Figure 2 zooms in Fig. 1 and only shows the technologies invented during the last 200 years.

Two types of red flags emerge from these figures. For 191 of the technology-country pairs for which we have a positive estimate of the slope, the predicted initial date of diffusion is before the invention date of the technology. For some technologies for which we do not have an invention date, such as hospital beds or irrigation, it is harder to determine precisely when a predicted initial adoption date is too early to be reasonable. Even after taking this fact into consideration, however, the estimated initial adoption dates are still implausibly early for some countries for these technologies. Taking a conservative invention date of 1000BC, we find an additional 11 technology-country pairs with implausibly early predicted adoption dates.

These implausible estimates reflect the fact that the diffusion of the technology does not follow a logistic pattern in these countries. More precisely, it likely happens because the identified diffusion curves are concave. When fitting a logistic to a curve that is concave, the steeper region of the curve will be fit near to inflexion point of the logistic, and, as a result, the predicted 1% adoption level will occur much earlier than the actual one. This can be seen in Fig. 3, which presents the actual diffusion of televisions in Canada (in solid) and the diffusion predicted by fitting a logistic (in dash).

The opposite situation, an unrealistically late predicted initial adoption date, also suggests the failure of the logistic approximation. Technically, this may occur for two different reasons. First, the diffusion data for the technology may be relatively flat initially with a slight

[3] For clarity we have not included in the plots the technologies already available in 1,500. The invention date of these technologies is more difficult to establish.

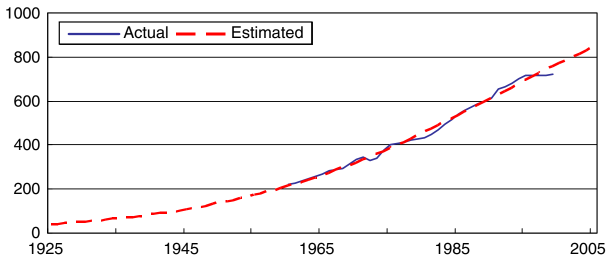


Fig. 3 Actual adoption curve of TVs in Canada and fitted logistic function

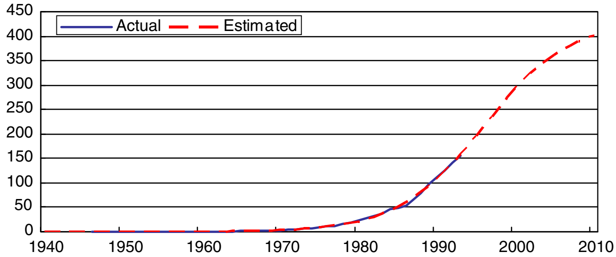


Fig. 4 Actual adoption curve of cars in Taiwan and fitted logistic function

acceleration at the end of the sample. The logistic interprets this acceleration as indication that the inflexion point has not yet been reached and places the predicted initial adoption date close to the first available observation; in some cases, the first observation in our data set may correspond to a date significantly after the invention. Figure 4 illustrates this argument with the diffusion of cars in Taiwan. Second, the logistic may predict an unrealistically late initial adoption date if the first observation in sample is significantly later than the invention date and if the slope of the diffusion data's curve is initially steep before flattening. As illustrated with the diffusion of newspapers in Germany in Fig. 5, the logistic fits the first observation near to the inflexion point. Since the curve is initially very steep, the predicted initial adoption date is close to the first observation. In reality, however, diffusion has not occurred symmetrically, and it has taken many years to reach the level at which our sample starts. In addition, the initial level in sample is substantially higher than 1% of the "estimated ceiling". As a result, the logistic predicts that the 1% adoption level is reached close to the beginning of sample, while, in reality, that level was reached long before.

The identification of these cases is a bit arbitrary since, as we have shown in Comin et al. (2006b), some countries tend to lag the technological leaders for as long as a century. Given that the existence of data for a technology implies that diffusion has begun, we assume that the 1% level must be reached soon after our initial observation. We will assume that the initial adoption date predicted by the logistic is unreasonably late if either it is at least 150 years after the invention date or at least 20 years after the first observation we have in sample for the pair.[4] We find 336 additional technology-country pairs are poorly approximated by the logistic in this respect (Table 3, row 5).

One final, critical property of S-shaped diffusion curves is that their convergence to a fixed ceiling. Once the intensive margin is included, this condition no longer necessarily holds. Indeed, as shown in Comin et al. (2006a), technological measures such as aviation passenger-kilometers, electricity, telephones, credit and debit card payments, and cell phones

[4] We omit the technologies without precise invention dates when identifying cases in which initial adoption falls more than 150 years after the invention date.

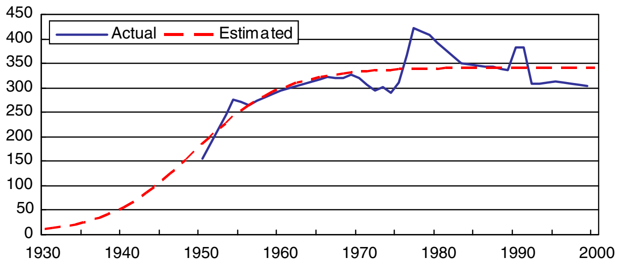


Fig. 5 Actual adoption curve of newspapers in Germany and fitted logistic function

violate this property. However, as with the share of negative estimates of δ_{3ij}, it is not trivial to determine exactly how many of our technology-country pairs have a moving ceiling. However, it seems reasonable to use a conservative standard and attempt to identify technologies that clearly fit this profile. To the list above we add steam and motor ship tonnage; rail passengers-kilometers; railway freight tonnage; tons of blast-oxygen furnace, electric-arc furnace, and stainless steel produced; cars; trucks; aviation freight ton-kilometers; TVs; PCs; credit and debit card points of service; ATMs; and cheques, all in per capita terms. The variable ceiling that characterizes a priori the diffusion of these technologies generates 1,098 additional deviations from the logistic pattern (row 6 in Table 3). This brings the total number of technology-country pairs for which the diffusion is not well characterized by the logistic to 3,381 out of the 5,678 technology-country pairs in our sample.[5] Hence, we conclude that once the intensive margin is included in the measure of technology diffusion, the S-shaped curves, and in particular the logistic, provide a poor description of the diffusion process.

3 Conclusion

The intensive margin is in principle as important as the extensive one in measuring the extent of the use of a new technology. In this paper we have described our CHAT data set, which contains measures of 115 technologies that incorporate both margins. This paper has also shown that it is important to include the intensive margin from an empirical reason. Once this is done, the logistic curve no longer seems to be a good approximation for the diffusion process. We leave for future work the exploration of more accurate representations.[6]

Appendix A: Underlying details

This appendix contains more detailed information about the CHAT data set and about the estimated rates of convergence presented in the main text. Tables A1, A2 and Fig. 1 provide detailed information about the coverage of the data that we use.

[5] There does not seem to be a relationship between the sample size and the probability of not fitting a logistic diffusion. We have divided the technology-country pairs into quintales based on the sample size. In all quintales the percentage failures is between 40 and 60%. Naturally, the failure to converge is more likely for the pairs in lowest sample size quintile (32%) than in those in the highest sample size quintile (16%). This is largely offset by the fact that we are more likely to find that the pairs in the highest sample size quintile do not have a fixed ceiling.

[6] Comin and Hobijn (2006, 2007) develop models whose reduced form predictions provide good approximation to the diffusion measures that include the intensive margin.

Table A1 Technologies per country

Afghanistan	16	Egypt	43	Lebanon	39	Saudi Arabia	34
Albania	21	El Salvador	34	Lesotho	16	Senegal	28
Algeria	44	Equatorial Guinea	9	Liberia	17	Serbia and Montenegro	18
Angola	26	Eritrea	3	Libya	28	Sierra Leone	21
Argentina	48	Estonia	20	Lithuania	19	Singapore	27
Armenia	14	Ethiopia	29	Luxembourg	10	Slovak Republic	39
Australia	68	Finland	95	Macedonia	16	Slovenia	22
Austria	70	France	82	Madagascar	29	Somalia	20
Azerbaijan	15	Gabon	20	Malawi	5	South Africa	44
Bangladesh	32	Gambia	18	Malaysia	37	South Korea	44
Belarus	16	Georgia	15	Mali	26	Spain	77
Belgium	78	Germany	87	Mauritania	22	Sri Lanka	37
Belize	4	Ghana	36	Mauritius	26	Sudan	29
Benin	26	Greece	61	Mexico	78	Suriname	4
Bolivia	29	Guatemala	27	Moldova	21	Swaziland	17
Bosnia-Herzegovina	17	Guinea	26	Mongolia	20	Sweden	83
Botswana	21	Guinea-Bissau	13	Morocco	36	Switzerland	59
Brazil	49	Guyana	20	Mozambique	24	Syria	33
Bulgaria	34	Haiti	17	Namibia	16	Taiwan	28
Burkina Faso	18	Honduras	29	Nepal	18	Tajikistan	13
Burma	34	Hong Kong	19	Netherlands	77	Tanzania	27
Burundi	20	Hungary	66	New Zealand	48	Thailand	40
Cambodia	27	Iceland	5	Nicaragua	28	Togo	27
Cameroon	29	India	50	Niger	19	Tunisia	34
Canada	77	Indonesia	39	Nigeria	37	Turkey	57
Central African Republic	20	Iran	41	North Korea	23	Turkmenistan	12
Chad	21	Iraq	34	Norway	65	Uganda	27
Chile	50	Ireland	81	Oman	21	Ukraine	24
China	49	Israel	38	Pakistan	42	United Arab Emirates	24
Colombia	45	Italy	75	Panama	27	United Kingdom	94
Costa Rica	26	Ivory Coast	31	Papua New Guinea	17	United States	80
Croatia	20	Japan	59	Paraguay	27	Uruguay	44
Cuba	40	Jordan	26	Peru	44	Uzbekistan	17
Czech Republic	39	Kazakhstan	17	Philippines	40	Venezuela	41
Czechoslovakia	36	Kenya	33	Poland	62	Vietnam	22
Dem. Rep. of the Congo	35	Korea	18	Portugal	82	Yemen	21
Denmark	84	Kuwait	25	Republic of the Congo	26	Yugoslavia	44
Dominican Republic	19	Kyrgyzstan	14	Romania	39	Zambia	28
East Germany	30	Laos	19	Russia	44	Zimbabwe	31
Ecuador	41	Latvia	22	Rwanda	16		

Table A2 Description of technologies and their coverage

Category	Variable name	Description	Country coverage (no.)	Date range	Source
Agriculture	Fertilizer consumed, total	Metric tons of fertilzer consumed. Aggregate of 25 individual types	All (149)	1965–2005	FAOSTAT
	Harvesters	Number of self-propelled machines that reap and thresh in one operation	All (116)	1965–2005	FAOSTAT
	Irrigated area	Area equipped to provide water to crops, including full/partial control irrigation and equipped wetland or inland valley bottoms	All (144)	1965–2005	FAOSTAT
	Milking machines	Number of installations consisting of several complete milking units	All (53)	1965–2005	FAOSTAT
	Percent of cultivated land using modern variety crops	Share, by area, of cropland planted with modern varieties	Developing (85)	1960–2000	Evenson
	Percent of irrigated land out of cultivated land	Irrigated area (as defined above) as a share of cultivated land, which includes land used for permanent/temporary crops and pasture	All (148)	1965–2005	FAOSTAT
	Pesticide consumed, total	Metric tons of active ingredients in pesticides used in or sold to the agricultural sector. Aggregate of 32 individual types	All (120)	1990–2000	FAOSTAT
	Tractors	Number of wheel and crawler tractors (excluding garden tractors) used	All (149)	1965–2005	FAOSTAT
Financial	ATMs	Number of electromechanical device that permits authorised users to withdraw cash from their accounts	Mostly OECD (33)	1990–2005	ECB, BIS
	Cheques issued	Number of payments by cheque	Mostly OECD (39)	1990–2005	ECB, BIS, EMEAP
	Debit and credit card transactions	Number of payments by debit or credit cards	Mostly OECD (37)	1990–2005	ECB, BIS, EMEAP

Table A2 continued

Category	Variable name	Description	Country coverage (no.)	Date range	Source
	Electronic funds transfers	Number of transactions using payment cards at points of service	Mostly OECD (34)	1990–2005	ECB, BIS
	Points of service for debit/credit cards	Number of retail locations at which payment cards can be used	Mostly OECD (35)	1990–2005	ECB, BIS
General	Electricity production	Gross output of electric energy (inclusive of electricity consumed in power stations) in KwHr	All (149)	1895–2005	Mitchell and WDI
	Internet users	Number of people with access to the worldwide network	All (146)	1990–2005	WDI
	Personal computers	Number of self-contained computers designed for use by one person	All (129)	1980–2005	WDI
Health	Appendectomies	Number of appendectomies performed	OECD (19)	1990–2005	OECD
	Beds: in-patient acute care	Number of beds for those seeking in-patient acute care, including diagnosis/treatment of an injury/illness and surgery	OECD (26)	1960–2005	OECD
	Beds: in-patient long-term care	Number of beds for people who need assistance on a continuing basis, including those in both hospitals and nursing homes	OECD (20)	1960–2005	OECD
	Beds: total hospital	Number of in-patient beds available in public/private hospitals and rehabilitation centers, for acute and chronic care	All (145)	1960–2005	WDI
	Bone marrow transplants	Number of bone marrow transplants performed	OECD (25)	1975–2005	OECD
	Breast conservation surgeries	Number of breast conservation surgeries performed	OECD (13)	1995–2005	OECD
	Caesarean sections	Number of Caesarean sections performed	OECD (19)	1990–2005	OECD
	Cardiac catheterizations	Number of cardiac catheterizations (insertion of a catheter into a chamber or vessel of the heart) performed	OECD (17)	1990–2005	OECD

Table A2 continued

Category	Variable name	Description	Country coverage (no.)	Date range	Source
	Cataract surgeries	Number of cataract surgeries performed	OECD (17)	1980–2005	OECD
	Cholecystectomies	Number of cholecystectomies (gallbladder removals) performed	OECD (16)	1980–2005	OECD
	Cholecystectomies, laparoscopic	Number of laparoscopic cholecystectomies (gallblader removals) performed. The laparoscopic method is less invasive	OECD (10)	1995–2005	OECD
	Computed tomography (CT) scanners	Number of computed tomography (CT) scanners	OECD (27)	1980–2005	OECD
	Coronary bypasses	Number of coronary bypass surgeries performed	OECD (23)	1990–2005	OECD
	Coronary interventions, percutaneous (PTCA and stenting)	Number of percutaneous coronary interventions (used to reduced or eliminate the symptoms of coronary artery disease) performed	OECD (24)	1990–2005	OECD
	Coronary stenting procedures	Number of coronary stenting procedures performed. This is a particular type of percutaneous coronary intervention	OECD (10)	1995–2005	OECD
	Dialysis patients	Number of patients receiving dialysis treatments	OECD (27)	1970–2005	OECD
	Dialysis patients, home	Number of patients receiving dialysis treatments at home	OECD (24)	1970–2005	OECD
	Heart transplants	Number of heart transplants performed	OECD (25)	1980–2005	OECD
	Hernia procedures, inguinal and femoral	Number procedures performed to correct inguinal and femoral hernias (the most common types)	OECD (17)	1980–2005	OECD
	Hip replacement surgeries	Number of hip replacement surgeries performed	OECD (20)	1990–2005	OECD
	Hysterectomies (vaginal only)	Number of vaginal hysterectomies performed (does not include abdominal or laparoscopic procedures)	OECD (20)	1990–2005	OECD
	Kidney transplants	Number of kidney transplants performed	OECD (27)	1965–2005	OECD
	Kidney transplants, functioning	Cumulative count of successful kidney transplants	OECD (25)	1970–2005	OECD
	Knee replacement surgeries	Number of knee replacement surgeries	OECD (15)	1990–2005	OECD

Table A2 continued

Category	Variable name	Description	Country coverage (no.)	Date range	Source
	Lithotripters	Number of extracorporeal shock wave lithotripters (used to break down kidney stones)	OECD (23)	1985–2005	OECD
	Liver transplants	Number of liver transplants performed	OECD (27)	1980–2005	OECD
	Lung transplants	Number of lung transplants performed	OECD (22)	1985–2005	OECD
	Mammographs	Number of dedicated mammography machines	OECD (15)	1970–2005	OECD
	Mastectomies	Number of mastectomies performed	OECD (18)	1990–2005	OECD
	MRI units	Number of magnetic resonance imaging (MRI) units	OECD (26)	1985–2005	OECD
	Pacemaker surgical procedures	Number of pacemaker implantation procedures performed	OECD (11)	1990–2005	OECD
	Percent immunized for DPT, children 12–23 months	Percent of children aged 12–23 months who received a DPT immunization (including all three doses) before the age of 1 year	All (153)	1980–2005	WDI
	Percent immunized for measles, children 12–23 months	Percent of children aged 12–23 months who received a measles immunization (one dose only) before the age of 1 year	All (153)	1980–2005	WDI
	Percent of beds for acute care	Percent of beds designated for acute care out of the total of acute and long-term care beds	OECD (21)	1960–2005	OECD
	Percent of cataract surgeries done as day cases	Percent of cataract surgeries performed without a hospital stay	OECD (14)	1990–2005	OECD
	Percent of cholecystectomies (laparoscopic) done as day cases	Percent of laparoscopic cholecystectomies performed without a hospital stay	OECD (9)	1995–2005	OECD
	Percent of cholecystectomies done as day cases	Percent of cholecystectomies performed without a hospital stay	OECD (11)	1995–2005	OECD
	Percent of dialysis patients at home	Percent of dialysis patients who receive treatment at home	OECD (25)	1970–2005	OECD
	Percent of hernia procedures done as day cases	Percent of hernia procedures performed without a hospital stay	OECD (14)	1995–2005	OECD

Table A2 continued

Category	Variable name	Description	Country coverage (no.)	Date range	Source
	Percent of tonsillectomies done as day cases	Percent of tonsillectomies performed without a hospital stay	OECD (12)	1995–2005	OECD
	Percent of varicose vein procedures done as day cases	Percent of varicose veins procedures performed without a hospital stay	OECD (14)	1995–2005	OECD
	Prostatectomies (excluding transurethral)	Number of non-transurethral prostatectomies performed (tend to include more advanced procedures)	OECD (14)	1990–2005	OECD
	Prostatectomies (transurethral)	Number of transurethral prostatectomies performed (most common procedure)	OECD (17)	1990–2005	OECD
	Radiation therapy equipment	Number of pieces of equipment for treatment with X-rays or radionuclide	OECD (24)	1960–2005	OECD
	Renal failure patients, end stage	Number of patients alive at end year who are receiving different forms of renal replacement therapy (including dialysis and/or a transplant)	OECD (25)	1970–2005	OECD
	Tonsillectomies	Number of tonsillectomies performed	OECD (13)	1980–2005	OECD
	Varicose vein procedures	Number of varicose vein correction procedures (including litigation and stripping) performed	OECD (12)	1995–2005	OECD
Steel	Percent of steel production by other methods	Percent of steel using methods not listed here—total determined by addition	All (23)	1930–2005	IISI
	Percent of steel production by the acid Bessemer method	Percent of steel using acid Bessemer method—total determined by addition	All (11)	1930–1975	IISI
	Percent of steel production by the basic Bessemer method	Percent of steel using basic Bessemer methods—total determined by addition	All (9)	1930–1980	IISI
	Percent of steel production in BOFs	Percent of steel using BOF methods—total determined by addition	All (58)	1960–2005	IISI
	Percent of steel production in EAFs	Percent of steel using EAF methods—total determined by addition	All (95)	1930–2005	IISI
	Percent of steel production in OHFs	Percent of steel using OHF methods—total determined by addition	All (53)	1930–2005	IISI

Table A2 continued

Category	Variable name	Description	Country coverage (no.)	Date range	Source
	Percent of steel production that is stainless	Percent of steel production (total of stainless and crude steel production) that is stainless—total determined by addition	All (24)	1985–1990	IISI
	Stainless steel production	Stainless steel production (in metric tons). Stainless steel has a different function	All (24)	1985–1990	IISI
	Steel production by other methods	Crude steel production (in metric tons) by methods other than those listed	All (23)	1930–2005	IISI
	Steel production by the acid Bessemer method	Crude steel production (in metric tons) by acid Bessemer process (an early steel process)	All (11)	1930–1975	IISI
	Steel production by the basic Bessemer method	Crude steel production (in metric tons) by basic Bessemer process (an early steel process)	All (8)	1930–1980	IISI
	Steel production in blast oxygen furnaces	Crude steel production (in metric tons) in blast oxygen furnaces (a process that replaced Bessemer and OHF processes)	All (56)	1960–2005	IISI
	Steel production in electric arc furnaces	Crude steel production (in metric tons) in electric arc furnaces (a process that complemented and improved upon Bessemer and OHF processes)	All (93)	1930–2005	IISI
	Steel production in open hearth furnaces	Crude steel production (in metric tons) in open hearth furnaces (a process that complemented the Bessemer process)	All (51)	1930–2005	IISI
Telecom	Cable television subscribers	Number of households that subscribe to a multichannel television service delivered by a fixed line connection	All (95)	1975–2005	WDI
	Cell phones	Number of users of portable cell phones	All (146)	1980–2005	WDI
	Mail items	Number of items mailed/received, with internal items counted one and cross-border items counted once for each country	All (79)	1830–1995	Mitchell
	Newspaper circulation (daily)	Number of newspaper copies circulated daily	All (153)	1950–2000	Banks
	Radios	Number of radios	All (149)	1925–2000	Banks

Table A2 continued

Category	Variable name	Description	Country coverage (no.)	Date range	Source
	Telegrams	Number of telegrams sent	All (78)	1850–1995	Mitchell
	Telephones	Number of mainline telephone lines connecting a customer's equipment to the public telephone network as of year end	All (152)	1880–2005	Mitchell and WDI
	TVs	Number of television sets in use	All (152)	1950–2005	Banks and WDI
Textiles	Automatic looms	Number of operable looms (of a certain size) in place at year end and are either automatic or have automatic attachments	All (96)	1965–1980	ICA
	Percent of automatic textile looms	Percent of total looms (sum of automatic and ordinary) that are automatic	All (98)	1965–1980	ICA
	Percent of spindles that are ring spindles	Percent of spinning spindles (ring and mule) in place and operable at year end that are ring spindles	All (31)	1905–1955	ICA
	Percent of textile raw materials that are unnatural	Percent of textile raw material fibers, consumed by spindles, that are either artificial or synthetics (as opposed to just raw cotton)	All (79)	1965–1980	ICA
	Spindles: mule	Number of mule spindles in place at year end	All (31)	1905–1955	ICA
	Spindles: ring	Number of ring spindles in place at year end	All (52)	1905–1955	ICA
Tourism	Hotel and other visitor beds	Number of visitor beds available in hotels and elsewhere	All (144)	1980–2005	WTO
	Hotel and other visitor rooms	Number of visitor rooms available in hotels and elsewhere	All (145)	1980–2005	WTO
Transportation	Aviation passenger kilometers	Civil aviation passenger-KM traveled on scheduled services by companies registered in the country concerned	All (109)	1920–1995	Mitchell
	Aviation ton-km of cargo	Civil aviation ton-KM of cargo carried on scheduled services by companies registered in the country concerned	All (103)	1930–1995	Mitchell

Table A2 continued

Category	Variable name	Description	Country coverage (no.)	Date range	Source
	Percent of ships that are steam and motor	Percent of all ships (as listed or as aggregated) that are powered by steam or motor	All (71)	1790–1995	Mitchell
	Percent of the tonnage of ships that are steam and motor	Percent by tonnage of all ships (as listed or as aggregated) that are powered by steam or motor	All (71)	1790–1995	Mitchell
	Railroads: freight ton-kilometers	Ton-KM of freight carried on railways (excluding livestock and passenger baggage)	All (100)	1850–1995	Mitchell
	Railroads: freight tons	Metric tons of freight carried on railways (excluding livestock and passenger baggage)	All (116)	1850–1995	Mitchell
	Railroads: length of line open	Geographical/route length of line open at year end. Industrial lines not open to the public generally excluded	All (126)	1830–1995	Mitchell
	Railroads: passenger journeys	Thousands of passenger journeys by railway	All (112)	1835–1995	Mitchell
	Railroads: passenger-journey km	Passenger journeys by railway in passenger-KM	All (94)	1840–1995	Mitchell
	Ships: motor	Number of motor ships (above a minimum weight) in use at midyear	All (8)	1910–1995	Mitchell
	Ships: sail	Number of sail ships (above a minimum weight) in use at midyear	All (31)	1820–1995	Mitchell
	Ships: steam	Number of steam ships (above a minimum weight) in use at midyear	All (20)	1820–1995	Mitchell
	Ships: steam and motor	Number of steam and motor ships (above a minimum weight) in use at midyear	All (57)	1870–1995	Mitchell
	Ships: total	Total number ships (above a minimum weight) in use at midyear	All (13)	1830–1995	Mitchell
	Tonnage of motor ships	Gross tonnage of motor ships (above a minimum weight) in use at midyear	All (8)	1910–1995	Mitchell
	Tonnage of sail ships	Gross tonnage (above a minimum weight) of sail ships in use at midyear	All (32)	1790–1995	Mitchell

Table A2 continued

Category	Variable name	Description	Country coverage (no.)	Date range	Source
	Tonnage of steam and motor ships	Gross tonnage (above a minimum weight) of steam and motor ships in use at midyear	All (59)	1870–1995	Mitchell
	Tonnage of steam ships	Gross tonnage (above a minimum weight) of steam ships in use at midyear	All (21)	1810–1995	Mitchell
	Tonnage of total ships	Gross tonnage of all ships (above a minimum weight) in use at midyear	All (13)	1830–1995	Mitchell
	Vehicles: commercial	Number of commercial vehicles, including buses and taxis (excluding tractors), in use	All (121)	1905–1995	Mitchell
	Vehicles: passenger cars	Number of passenger cars (excluding tractors and similar vehicles) in use	All (149)	1895–2005	Mitchell and WDI

Gross tonnage includes space that cannot be used by passengers or cargo, while net tonnage does not. All ship tonnage statistics are typically gross

OECD: Organization for economic co-operation and development; WDI: World development indicators; IISI: International Iron and Steel Institute; ECB: European central bank; ICA: International cotton association; International cotton association, WTO: World trade organization; BIS: Bank for International Settlements; EMEAP: Executive's Meeting of East Asia-Pacific Central Banks; FAOSTAT: Food and agriculture organization statistics

Table A1 lists the number of technologies we have for each of the countries in the data set. In our analysis we have to deal both with country fragmentations and reunification processes. When a majority of the territory remains after the fragmentation or a majority of the unified territory corresponds to just one of the pre-unification countries we identify the unified country with the big part. In cases of country fragmentation, we have identified a successor country in cases where a large portion of the territory remains as a single country; in cases of unification, we have identified a precursor country in a similar manner. Thus, Russia and the U.S.S.R have been treated as one national entity, as have Germany and West Germany. In cases where a country divides into or merges from a number of more equal pieces, we have chosen to treat the whole and the parts as different countries. Examples of this approach include Yugoslavia, Czechoslovakia, and Korea.

Table A2 describes for each technology the number of countries, the type of economies, and the time period covered.

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