INTERNATIONAL DIFFUSION OF NEW TECHNOLOGIES: INTENSIVE AND EXTENSIVE MARGINS

By
Anni-Maria Pulkki and Paul Stoneman*
Warwick Business School
University of Warwick
Coventry
CV4 7AL

This version March 3rd 2006

Abstract: It is argued that international diffusion involves two margins, the extensive and intensive respectively, reflecting usage extending to previously non using countries and to increasing usage in countries post first use. We show that the extensive margin only plays a major role in overall international diffusion in the early years of the diffusion process. In the later years it is the intensive margin that is important. The issue that is raised from this for future research is how the internal and external margins are linked. In particular: (i) is intra-country diffusion affected by inter-country diffusion or the extensive margin? – a question never asked, as far as we are aware, in the extensive body of domestic diffusion studies; and (ii) is inter–country diffusion affected by intra-country diffusion or the intensive margin?

JEL Classification: O3

Key words: Inter-country diffusion, intra-country diffusion

* Corresponding author: Tel +44 (0)2476 418408; e-mail Paul.Stoneman@warwick.ac.uk. We wish to thank the Economic and Social Research Council for their support of the research of Anni-Maria Pulkki.

1 INTRODUCTION

There is no clear definition in the literature as to precisely what is meant by the international diffusion of new technology, it is however natural to consider that it relates to changes over time in the extent to which world output is produced using, or world consumption is made up of products incorporating, a specific new technology. Examples would include the proportion of cars in the world produced using robots or the proportion of world televisions that incorporate HDTV. We label such measures as indicators of the overall diffusion of new technology. Overall diffusion is the result of two, possibly related, processes. The first concerns the extensive margin and relates to the spread of first use of a new technology across different countries (inter-country diffusion). Thus international diffusion may occur as a new technology is first used by firms or consumers in the United States, then Japan, then France, Germany and so on. It appears to us that the majority of the literature on the international diffusion of new technology is concerned with this extensive margin. The second process concerns the intensive margin and reflects the increasing extent to which the technology is used in different countries post first use (intra-country diffusion)[1]. It seems to us that the literature on international diffusion[2] rarely considers this dimension (e.g. see the review by Keller 2004).[3] However, in terms of welfare it will be the latter process that is most important, for it is only as technology is widely disseminated that substantial benefits arise.

This distinction between extensive and intensive margins has been picked up by Comin et al. (2006) where, inter alia, they also argue that the intensive margin has been largely ignored. In that paper[4] they analyse a number of related issues such as whether international diffusion is getting faster, whether overall diffusion is logistic and whether there are differences in inter-country adoption patterns for different technologies. Comin et al. (2006) are mostly concerned with the path of overall diffusion whereas our prime concern is with the relative importance of inter-country

[1] Much of the literature considers the study of international diffusion to involve just a comparison of national diffusion paths. That is not, a priori, appropriate.
[2] For a general survey of the diffusion literature see Stoneman (2002).
[3] It is however fair to say also that many national studies of diffusion consider the intensive margin but ignore the extensive.
[4] We may also note that Comin et al. (2006) have a larger data set available than that in Comin and Hobijn (2004a, b) which we use here.

and intra-country diffusion in the overall diffusion process and how this changes as overall diffusion proceeds. The approach taken here is similar to that of Battisti and Stoneman (2003) who explored the relative importance of inter-firm and intra-firm diffusion in overall industry diffusion. That previous exercise illustrated that although inter-firm diffusion was most commonly studied, intra-firm diffusion was in fact the main factor in overall diffusion for most of the study period.[5]

The data we use is from the Historical Cross-Country Technology Adoption Dataset (HCCTAD) collected by Diego A. Comin and Bart Hobijn.[6] The HCCTAD features panel data for 21 technologies in 23 countries with observations between 1788 and 2001. Various sources have been used to provide information on additional country-level variables such as population size, Gross Domestic Product, educational achievement, and other variables that capture aspects of the political and social environment. The data has been used for various analyses in Comin and Hobijn (2004a, b), but not in such an exercise as is performed here.

The paper proceeds by detailing the objectives and methods of analysis in the next section followed by a convenient example with very good data, the international diffusion of postal services, in section 3. We then extend to other technologies in section 4, discuss implications in section 5, and present our conclusions in section 6.

2 ANALYTICAL METHODS

The prime objective of this analysis is to explore the relative importance of inter-country and intra-country diffusion in the overall diffusion process of a new technology at different stages in that overall process.

Usage of new technology can be measured in a number of ways, three of which are most common: (i) total usage or ownership in time t, which we label $D^1(t)$; (ii) usage or ownership relative to some total output measure, e.g. Gross Domestic Product, which we label $D^2(t)$; and (iii) total usage relative to some estimated post-diffusion

[5] For the current study we fortunately also have better data available.

(asymptotic or saturation) level of usage. In this paper we do not want to become involved in actually estimating diffusion curves and thus concentrate upon the first two measures.

The extent of diffusion in any particular country, intra-country diffusion, is measured by the same indicator as overall diffusion but for the individual country. Defining this as $D^k(i,t)$, k =1,2 for country i, intra-country diffusion may be measured, for example, by usage or ownership relative to GDP in country i.

The appropriate measure of inter-country diffusion is the number (or proportion) of countries that are using the new technology at a level $D^k(i,t)$ in excess of some externally chosen base level D^{k*}. The most obvious choice for D^{k*} would be zero. However, data sources rarely pick up very first usage and there are considerable differences across countries in the level of usage that is first recorded. In order to make our analysis less sensitive to such differences in data availability, it is necessary to choose a positive D^{k*} for each given measure of diffusion (see further discussion below).

Let there be N(t) countries in total, of which M(t) in time t are users in the sense that intra-country diffusion exceeds D^{k*}. Define x(i,t) as total usage or ownership in country i at time t. If overall diffusion is to be measured by total usage or ownership then diffusion is simply the sum of x(i,t) across all M(t) using countries. Defining this sum as X(t), overall diffusion is given by

$$(1) \qquad D^1(t) = \sum_{i=1}^{M(t)} x(i,t) = X(t)$$

which can be written as

$$(2) \qquad D^1(t) = M(t) * \frac{X(t)}{M(t)}$$

[6] The HCCTAD has been made publicly available at http://www.nber.org/hccta.

with M(t) being an absolute measure of inter-country diffusion and X(t)/M(t) a measure of average intra-country diffusion equal to the average level of use across the using countries.

Alternatively, if overall diffusion is measured by usage or ownership relative to some measure such as GDP or total output, overall diffusion $D^2(t)$ will be given by total usage across all (using) countries X(t) relative to total output produced in all N(t) countries

$$(3) \qquad D^2(t) = \frac{\sum_{i=1}^{M(t)} x(i,t)}{\sum_{i=1}^{N(t)} y(i,t)}$$

where y(i,t) is output of country i at time t. Denoting total output of countries in the sample by Y(t) overall diffusion is given by

$$(4) \qquad D^2(t) = \frac{X(t)}{Y(t)}$$

which may be written as

$$(5) \qquad D^2(t) = \frac{M(t)}{N(t)} * \frac{X(t)/M(t)}{Y(t)/N(t)}$$

Here, M(t)/N(t) is a measure of the proportion of countries using the technology, an obvious inter-country measure and [X(t)/M(t)] / [Y(t)/N(t)] is average usage in using countries relative to the average output of all countries, a not quite so obvious intra-country diffusion measure . Thus for both $D^1(t)$ and $D^2(t)$ overall diffusion reflects two multiplicative indicators reflecting (i) the number or proportion of using countries and (ii) the average intensity of use in each country.

Denoting measures of inter-country diffusion by z(t) and measures of intra-country diffusion by w(t) we may express (2) and (5) as relationships between growth rates rather than levels by taking natural logarithms and differentiating with respect to time:

$$(6) \qquad d \ln D^k(t)/dt = d \ln z(t)/dt + d \ln w(t)/dt$$

The discrete time analogue is

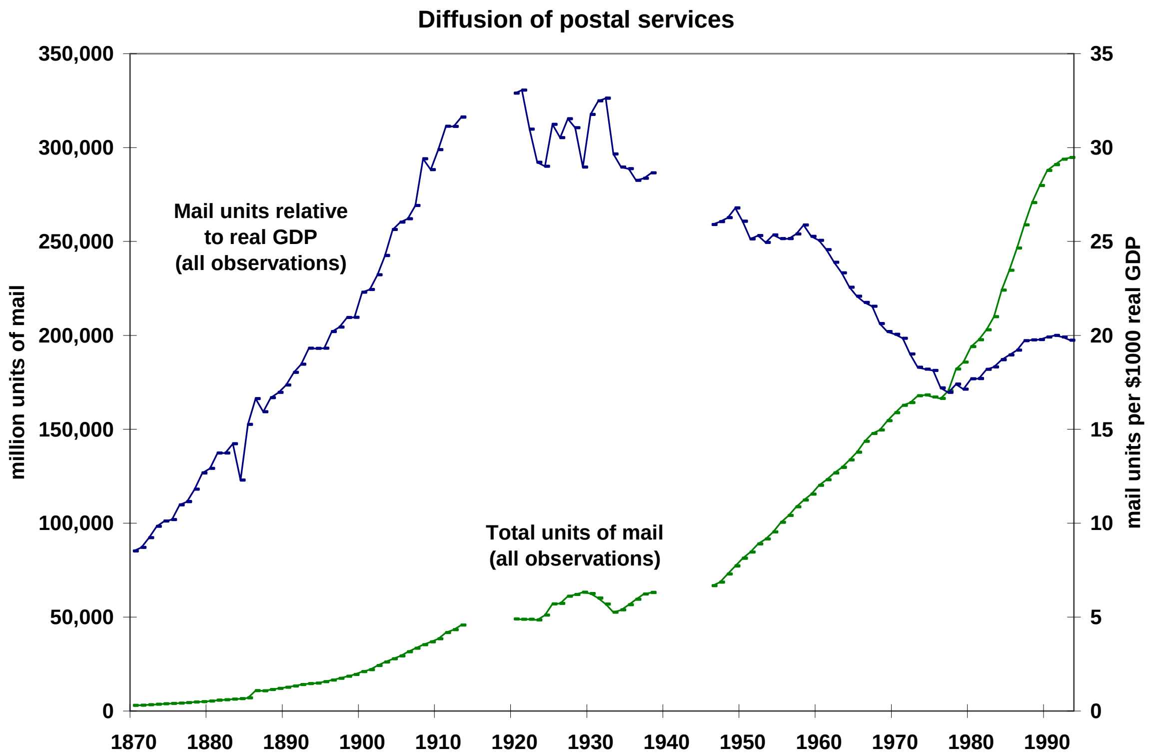
$$(7) \qquad \Delta \ln D^k(t) = \Delta \ln z(t) + \Delta \ln w(t)$$

Looking at growth in overall diffusion over a time period in this manner allows the analysis of the relative contributions of inter- and intra-country diffusion (Δ ln z(t) and Δ ln w(t) respectively) to overall diffusion.

3 A FIRST EXAMPLE

We take postal services as our first technology of interest primarily because the data is good and extensive. The HCCTAD provides annual data on the units of mail handled in up to 21 countries over the period 1830-1993. There are a considerable number of early observations (the earliest are for France and Austria in 1830) and from 1860 onwards annual figures are available for 15 countries or more without many consecutive missing observations. We consider two measures of diffusion, first the units of mail handled and second mail relative to GDP. Annual figures for GDP are available since 1870, but we also have information on GDP for the year 1850 for several countries. Until 1870 the amount of mail handled overall was generally low, and most of the growth in both the level of mail and the level relative to GDP has occurred since then. In Figure 1 we plot estimates of these two measures of diffusion since 1870. For this exercise we set D* equal to zero and the impact of missing observations has been smoothed out. This differs from our procedures below but serves to illustrate some of the differences between the two measures of diffusion. There has been a considerable increase in both total mail and mail relative to GDP, but the latter seems to have passed its peak while the former has continued to increase.

Figure 1: Total sample usage of postal services 1870-1993



To undertake a formal separation between the importance of inter- and intra-country effects in the illustrated overall diffusion process, as per the last section, we need first to consider some issues of data availability. The first issue is that for many of the countries in HCCTAD the first observation does not correspond with the very beginning of the diffusion process. This is a frequent occurrence in diffusion studies but is not necessarily a problem if it can be assumed that the level of usage in the unobserved period is below the arbitrary threshold level D*; that is, such countries in this period were effectively non-users. To this end we experiment with different values of D* for each measure of diffusion. An appropriate choice has to be low enough to justify the interpretation of D* as distinguishing users of a technology from non-users, but not so low that we are left with data on users alone (implying that no changes in inter-country diffusion can be captured). Also, an appropriate value should be high enough that the given measure of inter-country diffusion (equal to or a function of the number of users M(t)), $D^k(i,t)$, would be initially relatively low, and low enough that even countries in which usage never reaches a very high level can be considered users of the technology.

The second issue is that there are some countries (namely the United States, Japan, and Ireland) for which the level of usage at the first observation is so high that the countries cannot plausibly be regarded as non-users prior to that date but must be excluded from the analysis until that first observation.[7] Therefore we face the task of deciding which of the 21 countries in the HCCTAD can be included in the sample (determining N(t)). Clearly, with missing observations the sample size cannot be 21 for the whole period of analysis. The alternative of fixing N(t) at the number of countries for which data is available in say 1850 is also not attractive because the sample would be insufficient to represent "international" usage and more importantly because we would not capture the inter-country spread of technology over time. Finally, to let N(t) vary with the availability of data would imply that changes in (especially inter-country) diffusion would reflect increases in the availability of data over time. Fortunately, because our concern is with *changes* in overall, inter- and intra-country diffusion over a given time period, we can allow the sample size to vary between periods as long as it is kept fixed within each period. Such a measure of N(t) is also valid because we are interested in the relative (rather than absolute) contributions of inter- and intra-country diffusion to changes in overall diffusion.

Measuring the diffusion of postal services by total usage or ownership, i.e. $D^1(t)$ as defined above, we have decomposed the growth in overall diffusion for the period 1850-1990 using two alternative values for D^{1*} of 10 million and 50 million units of mail handled. With D^{1*} equal to 10 million we have sufficient data for 15 countries at the start of the period (i.e. N(t)=15). In 8 of these countries the amount of mail handled exceeded 10 million in 1850.[8] Initial overall diffusion (i.e. the total amount of mail handled in these 8 countries) was 812 million units and initial intra-country diffusion (i.e. average usage) was 102 million units. In 1990 all 15 countries were users with the overall level of diffusion equal to 82,954 million units.

[7] In particular, the earliest data for the United States is from 1886 (at 3747 million units) and Japan does not appear in the data set until 1902 (911 million), while e.g. for Greece we have a first figure of 800 000 units in 1840.

[8] The countries in the sample are: Austria, Belgium, France, Germany, Netherlands, Spain, Switzerland, United Kingdom (the users in 1850) and Australia, Denmark, Finland, Greece, New Zealand, Norway, Sweden (who become users during the period).

Applying equation (7) we obtain that 13.6% of the growth in overall diffusion was due to an increase in inter-country diffusion (that is an increase in the number of users M(t) from 8 to 15) and 86.4% was due to higher intra-country diffusion (that is an increase in average usage from 102 million to 5,530 million units). Taking D^1* equal to 50 million units the growth in overall diffusion between 1850 and 1990 decomposes such that 35.9% can be attributed to inter-country diffusion and 64.1% to intra-country diffusion.[9] This example suggests, not surprisingly, that in the long run, overall diffusion is primarily driven by an increasing intensity of usage within using countries.

Omitting the war years 1938-1950 because the amount of mail appears very volatile and several countries do not report any figures at all during these years[10] we have conducted the decomposition exercise as described above for each of the decades 1830-1990. The data is presented in Table 1, the two panels corresponding to D^1* equal to 10 and 50 million units respectively. As described above, we allow N(t) to vary across time but keep it fixed within each decade. N(t) is higher for the higher D^1* because we include some countries with no data as 'non-users' – these can be assumed to have a level of usage below 50 million (but not below 10 million). Missing data is approximated by values for a year in close proximity to the start of each decade where available, or by assuming linear growth if there are several consecutive missing observations.

[9] With D^1*=50 million the sample consists of 17 countries 3 of which were users in 1850.
[10] The extreme case is Canada for which no data is available for 1915-1947.

Table 1. Changes in overall diffusion $D^1(t)$, inter-country diffusion z(t) and intra-country diffusion w(t)

Panel A. D* = 10 million units of mail handled

Time period	Sample size	Level of diffusion						Growth of overall diffusion	Share of growth	
		Overall (million units)		Inter-country (users)		Intra-country (million units)			inter-country	intra-country
t, t+10	N	D(t)	D(t+10)	z(t)	z(t+10)	w(t)	w(t+10)	Δlog D(t)	Δlog z(t) /Δlog D(t)	Δlog w(t) /Δlog D(t)
1830-1840	10	127	182	2	2	64	91	0.357	0%	100%
1840-1850	11	353	668	3	4	118	167	0.639	45.1%	54.9%
1850-1860	15	812	1,585	8	9	102	176	0.669	17.6%	82.4%
1860-1870	16	1,693	2,892	10	12	169	241	0.535	34.1%	65.9%
1870-1880	17	2,917	5,311	13	15	224	354	0.599	23.9%	76.1%
1880-1890	18	5,339	8,563	16	18	334	476	0.472	24.9%	75.1%
1890-1900	19	12,568	21,056	19	19	661	1,108	0.516	0%	100%
1900-1910	20	21,967	38,493	20	20	1,098	1,925	0.561	0%	100%
1910-1920	20	38,493	49,717	20	20	1,925	2,486	0.256	0%	100%
1920-1930	20	49,172	62,515	20	20	2,459	3,126	0.240	0%	100%
1930-1938	20	62,515	64,012	20	20	3,126	3,201	0.024	0%	100%
1950-1960	21	81,268	120,088	21	21	3,870	5,718	0.390	0%	100%
1960-1970	21	120,088	158,748	21	21	5,718	7,559	0.279	0%	100%
1970-1980	21	158,748	194,042	21	21	7,559	9,240	0.201	0%	100%
1980-1990	20	187,875	281,637	20	20	9,394	14,082	0.405	0%	100%

Panel B. D* = 50 million units of mail handled

Time period	Sample size	Level of diffusion						Growth of overall diffusion	Share of growth	
		Overall (million units)		Inter-country (users)		Intra-country (million units)			inter-country	intra-country
t, t+10	N	D(t)	D(t+10)	z(t)	z(t+10)	w(t)	w(t+10)	Δlog D(t)	Δlog z(t) /Δlog D(t)	Δlog w(t) /Δlog D(t)
1830-1840	14	115	163	1	1	115	163	0.346	0%	100%
1840-1850	16	334	632	2	2	167	316	0.637	0%	100%
1850-1860	17	718	1,500	3	6	239	250	0.737	94.0%	6.0%
1860-1870	18	1,608	2,836	7	9	230	315	0.567	44.3%	55.7%
1870-1880	18	2,836	5,211	9	11	315	474	0.608	33.0%	67.0%
1880-1890	18	5,211	8,417	11	13	474	647	0.480	34.8%	65.2%
1890-1900	19	12,422	21,017	14	17	887	1,236	0.526	36.9%	63.1%
1900-1910	20	21,928	38,462	18	19	1,218	2,024	0.562	9.6%	90.4%
1910-1920	20	38,462	49,717	19	20	2,024	2,486	0.257	20.0%	80.0%
1920-1930	20	49,172	62,515	20	20	2,459	3,126	0.240	0%	100%
1930-1938	20	62,515	64,012	20	20	3,126	3,201	0.024	0%	100%
1950-1960	21	81,268	120,088	21	21	3,870	5,718	0.390	0%	100%
1960-1970	21	120,088	158,748	21	21	5,718	7,559	0.279	0%	100%
1970-1980	21	158,748	194,042	21	21	7,559	9,240	0.201	0%	100%
1980-1990	20	187,875	281,637	20	20	9,394	14,082	0.405	0%	100%

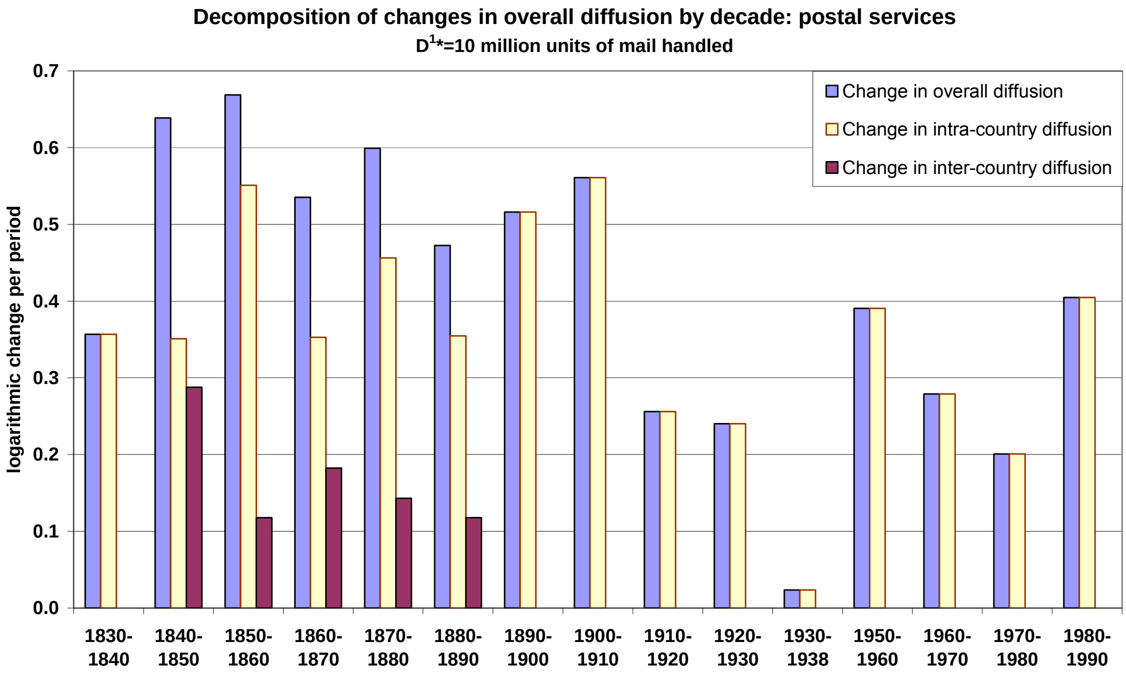
Notes to Table 1. Overall diffusion $D^1(t)$ is measured by million units of mail handled in all countries M(t) that are users, X(t). Inter-country diffusion z(t) is the number M(t) computed for D^{1*} equal to 10 million and 50 million units of mail in panels A and B respectively. Intra-country diffusion w(t) is computed as the average amount of mail in all using countries measured as X(t)/M(t).

Table 1 reveals that overall diffusion and average usage have increased continuously throughout the period. The growth in the decade 1980-1990 is particularly striking because our data does not include telefaxes or electronic mail, which, as substitute technologies, we anticipate would reduce demand for traditional mail. There were no increases in inter-country diffusion after 1890 (1920) for D^1* equal to 10 million (50 million).

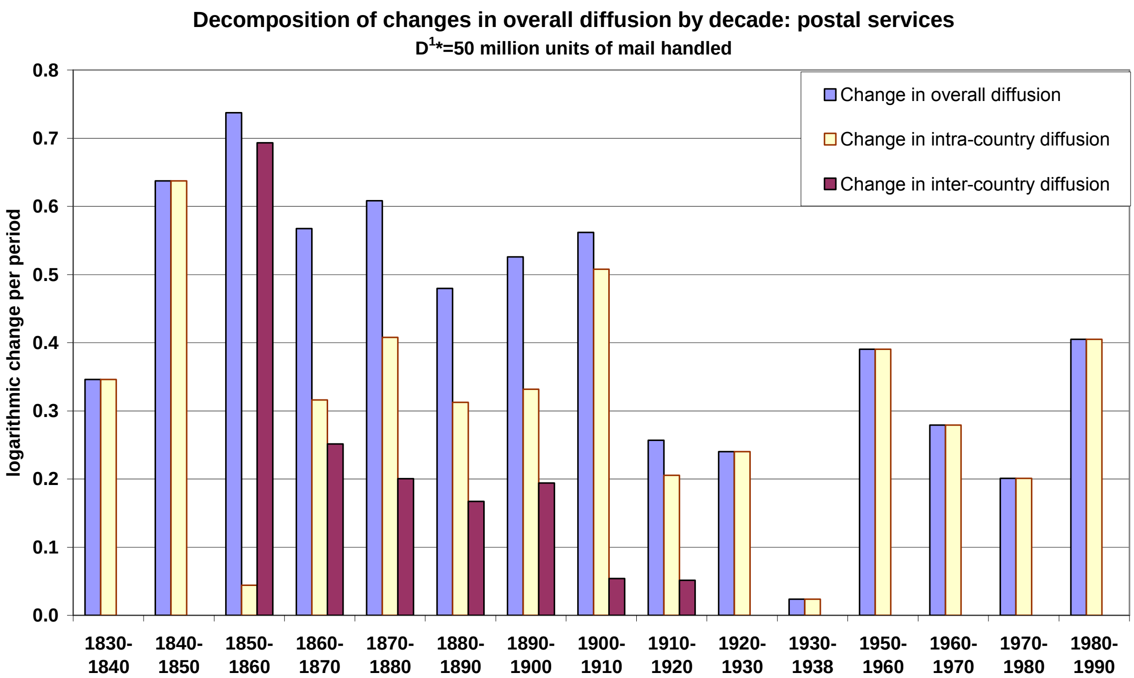
Using these estimates and applying equation (7) we plot changes in the log of the overall, inter- and intra-country usage measures in Figure 2. We observe first that growth in overall diffusion has tended to be smaller in the second half of the observation period. Secondly, we note that inter-country diffusion slowed as the diffusion process proceeded, especially when D^1* is set at 50 million units.

Figure 2. Decomposition of changes in $D^1(t)$

Panel A.



Panel B.

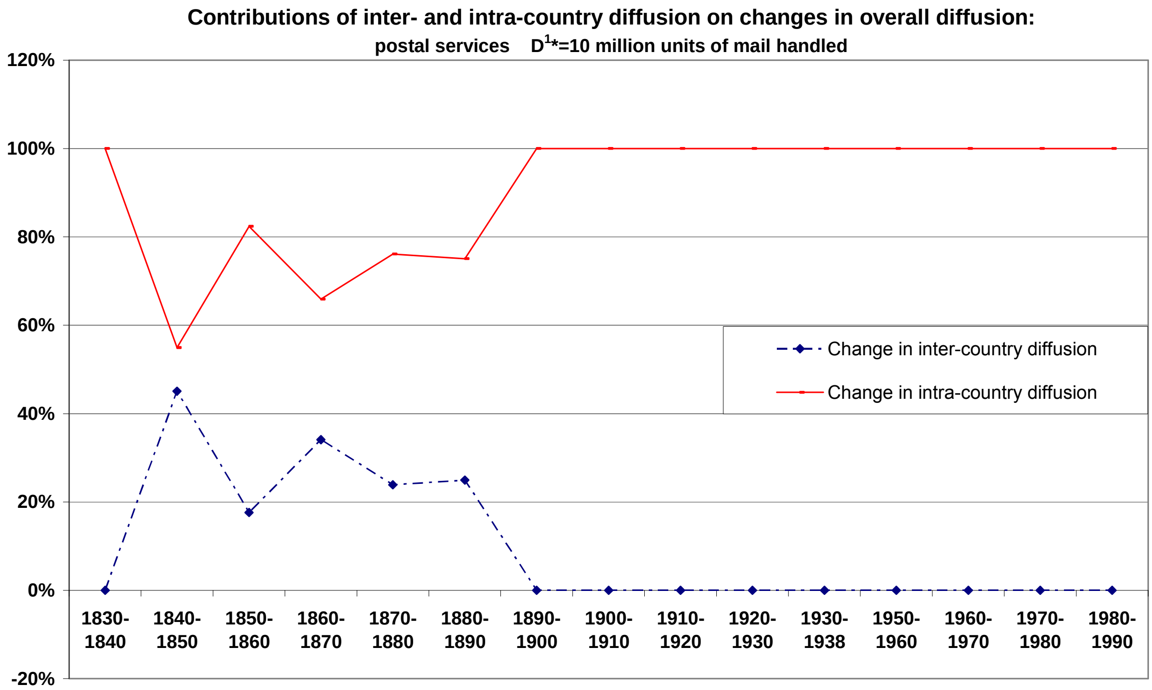


Notes to Figure 2. Change in overall diffusion is computed from the data in Table 1 as log $D^1(t+10)$ – log $D^1(t)$. Change in inter-country diffusion is log M(t+10) – log M(t). Change in intra-country diffusion is log [X(t+10)/M(t+10)] – log [X(t)/M(t)].

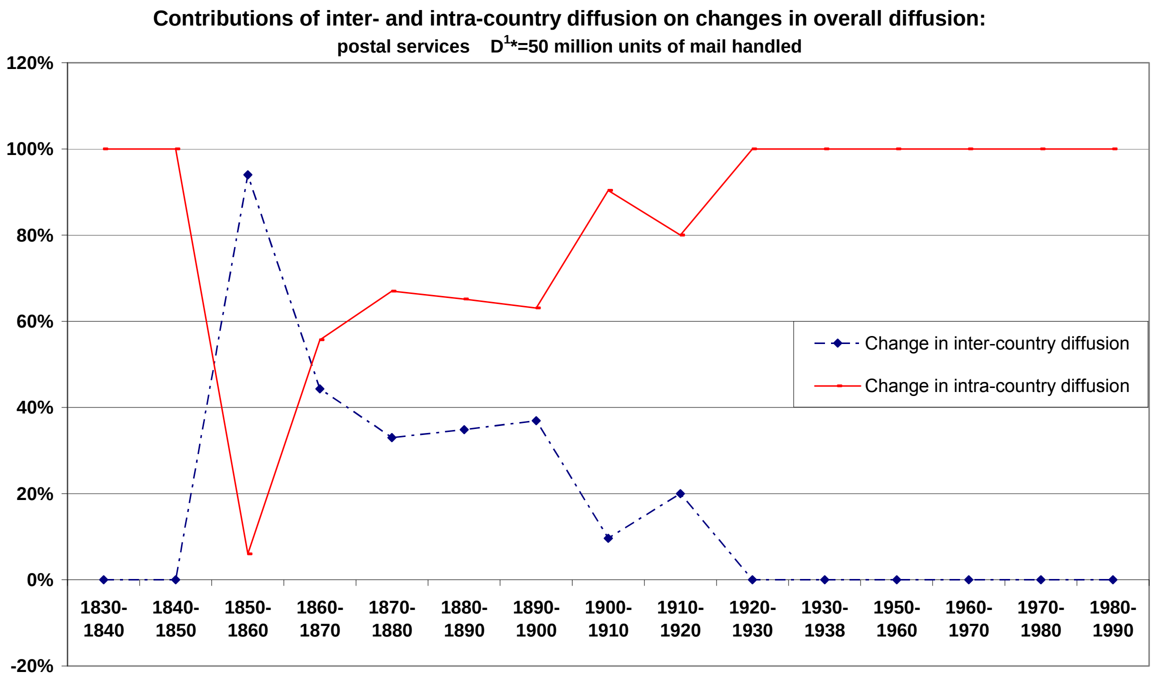
In Figure 3 we plot the percentage contribution of changes in inter- and intra-country diffusion to the growth of overall diffusion. We observe that after the initial decades in which the number of users was constant changes in inter-country diffusion accounted for nearly 50 per cent of overall diffusion. As diffusion (and time) proceeded changes in intra-country diffusion began to dominate the overall growth process. The declining importance of inter-country diffusion is especially evident for D^{1*} equal to 50 million after the decade 1850 – 1860 during which 94 per cent of overall growth was due to an increase in the number of users.

Figure 3. Relative contributions of changes in z(t) and w(t) on changes in $D^1(t)$

Panel A.



Panel B.



Notes to Figure 3. The contribution of changes in inter-country diffusion is computed from the data in Table 1 as [log z(t+10) – log z(t)] / [log $D^1(t+10)$ – log $D^1(t)$] for each decade. Similarly the contribution of changes in intra-country diffusion is [log w(t+10) – log w(t)] / [log $D^1(t+10)$ – log $D^1(t)$].

We now repeat the decomposition exercise using $D^2(t)$ as in equation (5) measuring the diffusion of postal services in country i by units of mail handled x(i,t) relative to real GDP y(i,t). From HCCTAD we measure GDP in 1990 international Stone-Geary dollars. A country is defined as a user if x(i,t)/y(i,t) exceeds the base level D^{2*} which we set at 5 units of mail per $1000 real GDP.

In Table 2 below we present the data for each of the decades 1850 – 1990 omitting the war years 1938 – 1950 as above. All three measures of diffusion, overall, inter and intra, grew until 1920 (with the exception of intra-country diffusion which declined 1850 – 1860). In the following decades up to but excluding 1980 – 1990, overall diffusion fell because sample average usage was falling, i.e. GDP was growing more than proportionally to the amount of mail. However, in the last decade, 1980 – 1990, the increase in mail was so considerable that our measure of overall diffusion $D^2(t)$ also increased (compare Table 1). This occurred despite a reduction in inter-country diffusion (which was due to x(i,t)/y(i,t) dropping below D^{2*} in one country).[11] Changes in logs of overall, inter-, and intra-country diffusion by decade are plotted in Figure 4, from which it is immediately clear that overall diffusion grew fastest in the early decades of the study period. Changes in inter-country diffusion follow a similar (and perhaps even more pronounced) pattern to that found above for $D^1(t)$. That is, increases in inter-country diffusion were large in the first three sample decades, but since then the ratio M(t)/N(t) has changed very little if at all.

[11] All changes in intra-country diffusion in 1960-1990 were due to Greece. Greece proved a difficulty for our analysis since usage x(i,t)/y(i,t) was very low throughout the period. We experimented with lower values of D^{2*} but data availability for other countries suggested that 5 units per $1000 was the most appropriate choice.

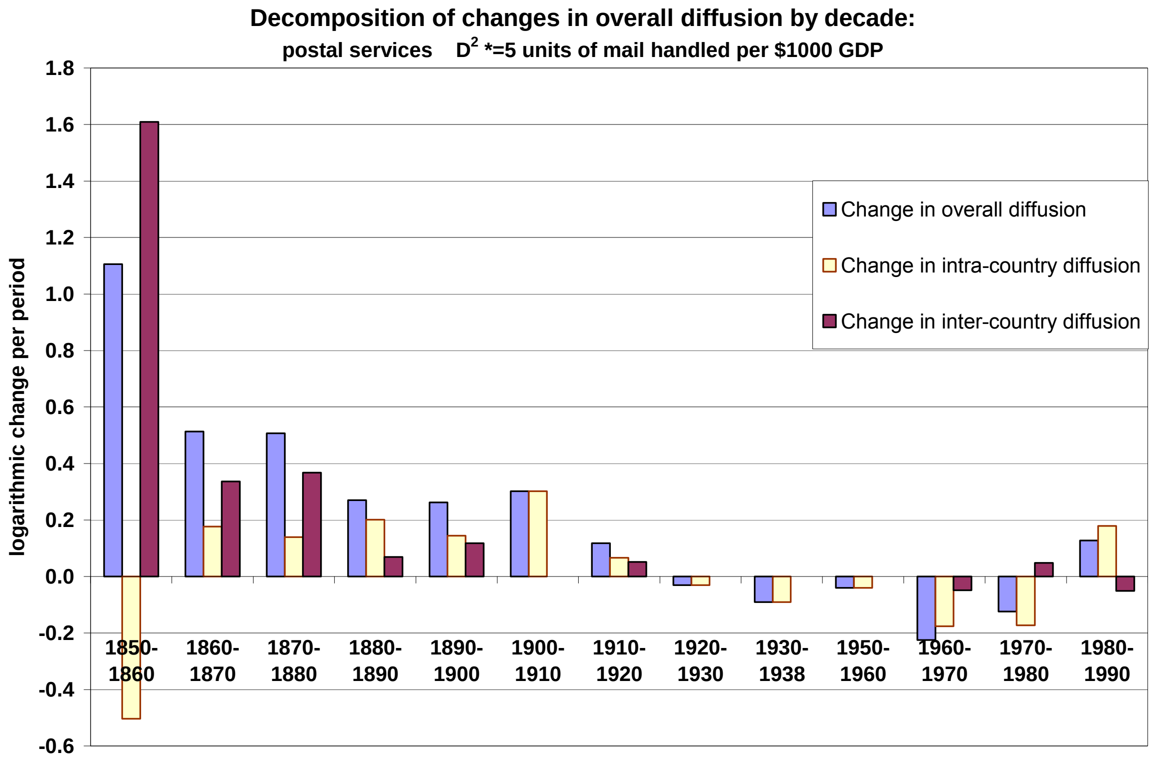
Table 2. Changes in overall diffusion $D^2(t)$, inter-country diffusion z(t) and intra-country diffusion w(t)

D*=5 units of mail handled per $1000 real GDP

Time period	Sample size	Mail (million units)		Level of diffusion: Overall (mail/$1000 GDP)		Level of diffusion: Inter-country (user proportion)		Level of diffusion: Intra-country (mail/$1000 GDP)		Growth of overall diffusion	Share of growth: inter-country	Share of growth: intra-country
t, t+10	N	X(t)	X(t+10)	D(t)	D(t+10)	z(t)	z(t+10)	w(t)	w(t+10)	Δlog D(t)	Δlog z(t) /Δlog D(t)	Δlog w(t) /Δlog D(t)
1850-1860	13	350	1,288	1.7	5.2	0.08	0.38	22.2	13.4	1.106	145.5%	-45.5%
1860-1870	13	1,288	2,538	5.2	8.6	0.38	0.54	13.4	16.0	0.513	65.6%	34.4%
1870-1880	17	2,602	5,182	7.6	12.5	0.53	0.76	14.3	16.4	0.507	72.6%	27.4%
1880-1890	17	5,210	8,377	12.6	16.5	0.82	0.88	15.3	18.7	0.270	25.5%	74.5%
1890-1900	18	12,382	21,040	17.2	22.3	0.89	1	19.3	22.3	0.262	44.9%	55.1%
1900-1910	19	21,951	38,462	22.1	29.9	1	1	22.1	29.9	0.302	0%	100%
1910-1920	20	38,462	49,717	29.7	33.4	0.95	1	31.2	33.4	0.118	43.6%	56.4%
1920-1930	20	49,172	62,515	33.6	32.6	1	1	33.6	32.6	-0.031	0%	100%
1930-1938	20	62,515	64,012	32.6	29.7	1	1	32.6	29.7	-0.090	0%	100%
1950-1960	21	81,268	120,088	26.1	25.1	1	1	26.1	25.1	-0.040	0%	100%
1960-1970	21	120,088	158,478	25.1	20.0	1	1	25.1	21.0	-0.225	21.7%	78.3%
1970-1980	21	158,478	194,042	20.0	17.7	1	1	21.0	17.7	-0.124	-39.4%	139.4%
1980-1990	20	187,875	281,199	17.8	20.2	1	1	17.8	21.2	0.128	-40.2%	140.2%

Notes to Table 2. Overall diffusion $D^2(t)$ is measured by units of mail handled per $1000 real GDP in 1990 international Stone-Geary dollars. Inter-country diffusion z(t) is the proportion M(t)/N(t). Intra-country diffusion w(t) is the average amount of mail in all using countries divided by the average real GDP across all countries N(t), that is $w(t) = [X(t)/M(t)] / [Y(t)/N(t)]$ where $X(t) = \sum^{M(t)} x(i,t)$ and $Y(t) = \sum^{N(t)} y(i,t)$.

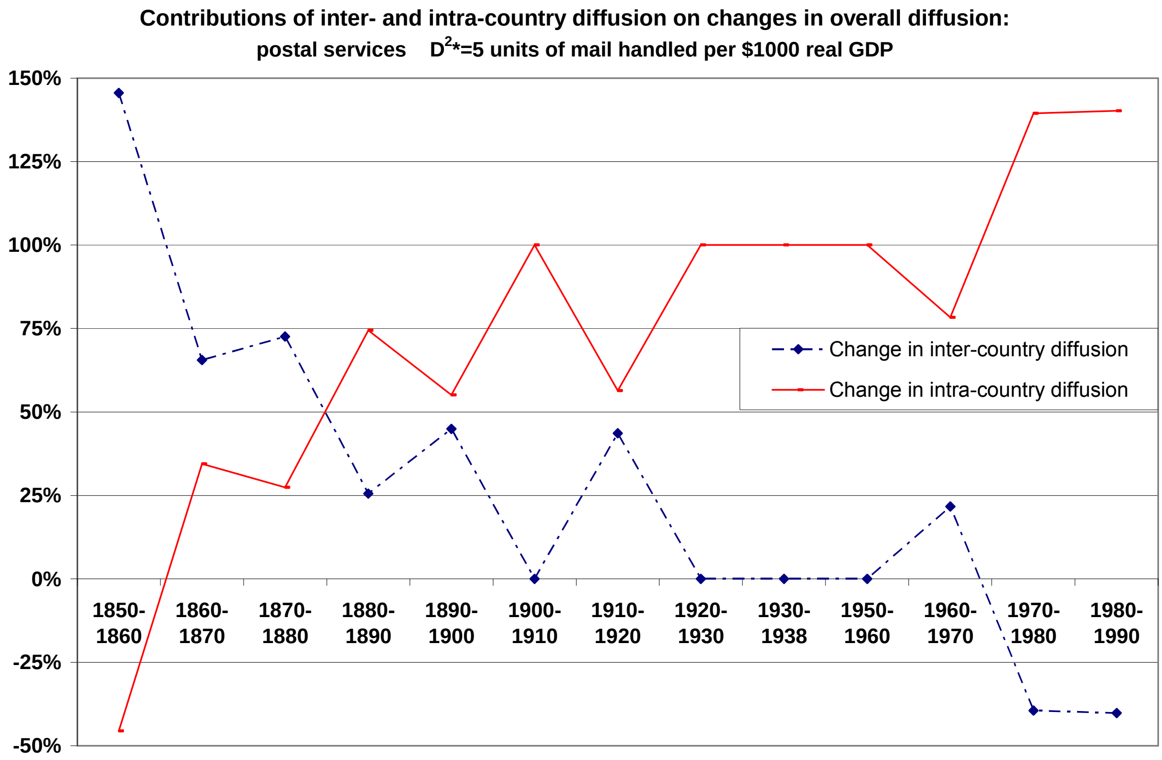
Figure 4. Decomposition of changes in $D^2(t)$



Notes to Figure 4. Change in overall diffusion is computed from the data in Table 2 as $\log D^2(t+10) - \log D^2(t)$. Change in inter-country diffusion is $\log (M(t+10)/N) - \log (M(t)/N)$ where N is held constant for each decade. Change in intra-country diffusion is $\log\{[X(t+10)/M(t+10)]/[Y(t+10)/N]\} - \log\{[X(t)/M(t)]/[Y(t)/N]\}$.

Finally we plot the percentage contribution of changes in inter- and intra-country diffusion to growth in overall diffusion (Figure 5). A very similar pattern emerges as above for $D^1(t)$. Namely, while growth in the number of users was driving changes in overall diffusion in the first three decades (1850 – 1880) since then it has been the increasing intensity of usage by existing users that has dominated.

Figure 5. Relative contributions of changes in z(t) and w(t) on changes in $D^2(t)$



Notes to Figure 5. The contribution of changes in inter-country diffusion is calculated from the data in Table 2 as [log z(t+10) – log z(t)] / [log D^2(t+10) – log D^2(t)] for each decade. Similarly the contribution of changes in intra-country diffusion is [log w(t+10) – log w(t)] / [log D^2(t+10) – log D^2(t)].

4 OTHER TECHNOLOGIES.

In order to confirm that our findings are not technology specific we have undertaken similar exercises for three other technologies in the HCCTAD data set (although had others been chosen the essence of the results would have been no different). The three are electricity, telephones and the basic oxygen steel making processes. Diffusion in these we measure respectively by megawatt hours of electricity output, the number of telephone lines, and tonnes of steel produced. In each case we have undertaken the analysis using both $D^1(t)$ and $D^2(t)$ diffusion indicators. For brevity however we present only results for $D^2(t)$ measures which look at usage relative to an indicator of total output.

4.1 Electricity

In Table 3 we present the results relating to the diffusion of electricity measured as megawatt hours of electricity output relative to GDP. D^2* is chosen as 0.50 mwhrs per million dollars real GDP). Clearly since 1900 through to the end of the period world electricity output relative to GDP has increased continuously. Inter-country diffusion however was complete in this sample of countries by around 1950 after which all further extensions of use reflected greater intra-country diffusion. This is illustrated also by the fact that, by the 1930s, extensions of intra-country diffusion were already contributing more to overall diffusion than further inter-country diffusion.

Table 3: The diffusion of electricity (1900 – 1998)

D^2*= 0.50 mwhrs per $1 million real GDP

Time period	Sample size	Electricity output (100 mwhrs)		Level of diffusion: Overall (mwhrs/$m GDP)		Inter-country (user proportion)		Intra-country (mwhrs/$m GDP)		Growth of overall diffusion	Share of growth: inter-country	intra-country
t, t+10	N	X(t)	X(t+10)	D(t)	D(t+10)	z(t)	z(t+10)	w(t)	w(t+10)	Δlog D(t)	Δlog z(t) /Δlog D(t)	Δlog w(t) /Δlog D(t)
1900-1910	14	0	691	0	0.06	0	0.07		0.80	-	-	-
1910-1920	15	691	7,744	0.06	0.55	0.07	0.20	0.85	2.76	2.271	48.4%	51.6%
1920-1930	20	9,648	25,803	0.65	1.32	0.40	0.75	1.62	1.75	0.709	88.6%	11.4%
1930-1938	21	25,881	37,216	1.32	1.69	0.76	0.86	1.73	1.97	0.251	46.9%	53.1%
1938-1950	21	37,216	74,083	1.69	2.38	0.86	0.95	1.97	2.50	0.341	30.9%	69.1%
1950-1960	21	74,083	162,223	2.38	3.39	0.95	1	2.50	3.39	0.354	13.8%	86.2%
1960-1970	21	162,223	344,751	3.39	4.35	1	1	3.39	4.35	0.252	0%	100%
1970-1980	21	344,751	529,466	4.35	4.83	1	1	4.35	4.83	0.103	0%	100%
1980-1990	21	529,466	701,783	4.83	4.85	1	1	4.83	4.85	0.006	0%	100%
1990-1998	21	701,783	827,901	4.85	5.29	1	1	4.85	5.29	0.085	0%	100%

4.4 Fixed line telephony.

In Table 4 we present the data relating to fixed line telephony measuring diffusion by the number of telephone lines relative to GDP. D^2* is chosen as 1 mainland telephone per one million dollars real GDP. Once again overall diffusion, beginning around 1900, has been continuously extending. However the inter-country spread was complete by 1930, and all growth beyond that date has been through extending intra-country usage.

Table 4: The diffusion of mainland telephones (1890 – 1998)

D^2*= 1 mainland telephone line per $1 million real GDP

Time period	Sample size	Blast oxygen output (1000 tonnes)		Level of diffusion: Overall (% oxygen)		Level of diffusion: Inter-country (user proportion)		Level of diffusion: Intra-country (% oxygen)		Growth of overall diffusion	Share of growth: inter-country	Share of growth: intra-country
t, t+5	N	X(t)	X(t+5)	D(t)	D(t+5)	z(t)	z(t+10)	w(t)	w(t+10)	Δlog D(t)	Δlog z(t) /Δlog D(t)	Δlog w(t) /Δlog D(t)
1960-1965	13	5,037	68,843	2.3%	24.1%	0.23	0.92	10.0%	26.1%	2.347	59.1%	40.9%
1965-1970	13	68,843	198,851	24.1%	54.0%	0.92	1	26.1%	54.0%	0.806	9.9%	90.1%
1970-1975	15	205,628	250,975	53.3%	67.3%	1	1	53.3%	67.3%	0.235	0%	100%
1975-1980	16	251,276	259,688	67.3%	68.5%	1	1	67.3%	68.5%	0.017	0%	100%
1980-1985	16	259,688	243,208	68.5%	69.2%	1	1	68.5%	69.2%	0.010	0%	100%
1985-1990	16	243,208	246,020	69.2%	67.2%	1	1	69.2%	67.2%	-0.030	0%	100%
1990-1995	16	246,020	232,303	67.2%	62.1%	1	1	67.2%	62.1%	-0.079	0%	100%
1995-2000	16	232,303	243,836	62.1%	62.0%	1	0.94	62.1%	66.1%	-0.001	6699%	-6599%

4.3 The basic oxygen steel making process

Finally we look at usage of the basic oxygen steel making process, this time conducting the exercise over 5-year periods. Here we measure diffusion by the proportion of all crude steel produced using the blast oxygen furnace with D^2* chosen as 10 per cent. The data is reproduced in Table 5. The revealed pattern is now the familiar one. By 1970 inter-country diffusion had been completed and all diffusion after that date reflected increased intra-country usage. In this case however overall diffusion had peaked in the late 1980s after which the extent of usage declined. That decline was the result of declining intra-country usage in 1985 – 1995 and the abandonment of the technology by one country (Luxembourg) after 1997.

Table 5. The diffusion of the basic oxygen process (1960 - 2000)

D^2*= 10% of crude steel produced using the blast oxygen furnace

Time period	Sample size	Telephones (1000 lines)		Level of diffusion: Overall (lines/$m GDP)		Inter-country (user proportion)		Intra-country (lines/$m GDP)		Growth of overall diffusion	Share of growth: inter-country	intra-country
t, t+10	N	X(t)	X(t+10)	D(t)	D(t+10)	z(t)	z(t+10)	w(t)	w(t+10)	Δlog D(t)	Δlog z(t) /Δlog D(t)	Δlog w(t) /Δlog D(t)
1890-1900	13	0	1,062	0	1.1	0	0.46	0	2.4	-	-	-
1900-1910	16	1,133	5,555	1.2	4.5	0.56	0.75	2.1	5.9	1.336	21.5%	78.5%
1910-1920	18	5,746	11,288	4.5	7.7	0.72	0.83	6.2	9.2	0.536	26.7%	73.3%
1920-1930	21	11,329	19,301	7.6	9.8	0.86	1	8.8	10.3	0.259	40.6%	59.4%
1930-1938	21	19,301	22,167	9.8	10.1	1	1	10.3	10.6	0.026	0%	100%
1938-1950	21	22,200	39,576	10.1	12.7	1	1	10.1	12.7	0.231	0%	100%
1950-1960	21	39,576	73,290	12.7	15.3	1	1	12.7	15.3	0.186	0%	100%
1960-1970	21	73,290	139,782	15.3	17.7	1	1	15.3	17.7	0.143	0%	100%
1970-1980	21	139,782	256,262	17.7	23.4	1	1	17.7	23.4	0.280	0%	100%
1980-1990	21	256,262	376,995	23.4	26.1	1	1	23.4	26.1	0.110	0%	100%
1990-1998	21	376,995	485,188	26.1	28.2	1	1	26.1	28.2	0.079	0%	100%

5 CONCLUSIONS, LIMITATIONS AND IMPLICATIONS

We have argued that international diffusion involves two margins – the extensive and the intensive. The former reflects usage extending to previously non using countries, the latter refers to increasing usage in countries post first use. The majority of the literature on international diffusion considers only the extensive margin. We have shown however that the extensive margin only plays a major role in international diffusion in the early years of the diffusion process. In the later years it is the intensive margin that is important. Thus in the early part of the diffusion process the inter-country spread of a technology is the more important in the diffusion process while in the later years it is mainly intra-country diffusion that is important. This is equivalent to the findings of Battisti and Stoneman (2003) that in the early stages inter-firm diffusion is most important in industry diffusion but in later stages intra-firm diffusion dominates.

These results have been generated looking at several technologies taken from the HCCTAD and of course are specific to that data base. We see no reason however why the findings cannot be generalised. There is now a new extended version of this data base (known as CHAT) that extends to 115 technologies and 150 countries over 200 years (see Comin et al. 2006), but that data is not available to us at this time. It would be useful at some future date to see if our results still hold for this larger sample.

The relative importance of the internal and external margins provides a more solid foundation upon which to evaluate the international competitiveness of different countries and also suggests how one may better compare relative diffusion performance across different countries (for an earlier approach to this see Canepa and Stoneman, 2004). Perhaps more important however are the implications of our findings for future research in this area. The implication that seems most important to us is that the above is only an accounting exercise. It provides no information upon the forces that drive diffusion. We consider of prime importance to be how the internal and external margins are linked. In particular: (i) is intra-country diffusion affected by inter-country diffusion or the extensive margin? – a question never asked in the extensive body of domestic diffusion studies as far as we are aware; and (ii) is inter-country diffusion affected by intra-country diffusion or the intensive margin? – again a question we do not recall seeing before. These seem to us to be crucial questions in understanding the overall diffusion process.

REFERENCES

Battisti G and Stoneman P (2003), 'Inter- and intra-firm effects in the diffusion of new process technology' *Research Policy,* 32(9), pp. 1641-1655.

Canepa A and Stoneman P (2004), 'Comparative International Diffusion: Patterns, Determinants and Policies', *Economics of Innovation and New Technology*, 13(3), pp. 279-298.

Comin D and Hobijn B (2004a), 'Cross-country technological adoption: making the theories face the facts' *Journal of Monetary Economics*, 51(1), pp. 39-83.

Comin D and Hobijn B (2004b), 'Neoclassical Growth and the Adoption of Technologies', *NBER Working Paper*, 10733, August, Cambridge, Mass.

Comin D, B Hobijn and E Rovito (2006), 'Five Facts you need to know about technology diffusion', *NBER Working Paper*, 11928, January, Cambridge, Mass.

Keller, W (2004), 'International Technology Diffusion' *Journal of Economic Literature,* 42(3), pp. 752-782.

Stoneman P (2002), *The Economics of Technological Diffusion*, Blackwell, Oxford.