On the Patterns and Determinants of the Global Diffusion of New Technologies

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Abstract

Taking a largely empirical approach this paper addresses the global spread of new technologies by defining two diffusion margins – the extensive, referring to the spreading of first use across economies and the intensive, referring to the intensity of use within economies. Using data relating to mail services we indicate the relative importance of the intensive and extensive margins in global diffusion over time. Using data on steamships and the basic oxygen process for steelmaking we also explore whether there are international spillovers in the diffusion process. We find evidence of spillovers which appear more likely to be negative than positive.

Keywords

Innovation diffusion; international; historical; mail services; steam ships; basic oxygen.

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1. Introduction

The benefits of new product and process technologies only arise as those technologies are diffused i.e. spread across their potential markets. In many cases these markets are global and technology eventually encompasses the whole world. However, as Battisti and Stoneman (2010) argue, the literature on the diffusion of new technology, with some exceptions of course (e.g. Grossman and Helpman, 1993; Perkins and Neumayer, 2005), tends to take little note of patterns and determinants beyond national boundaries. Although there is a considerable literature on diffusion at the industry level, the firm level, and the national level, most of this literature implicitly appears to ignore events outside the domestic economy. Even the literature that undertakes international comparisons of diffusion in different countries largely treats each country as a freestanding unit rather than part of a global economy.

Taking a largely empirical approach this paper addresses the global spread of new technologies by defining two diffusion margins – the extensive, referring to the spreading of first use across economies and the intensive, referring to the intensity of use within economies. The empirical work is based upon data in the Historical Cross Country Technology Adoption Data Set (HCCTAD) collected by Comin and Hobijn (2003, 2004).[1]

We first explore changes in the two defined margins over time and their relative contribution to changes in the extent of worldwide use over the diffusion time profile. Using the history of mail services (1830 – 1990) as an example, we find that diffusion at the extensive margin is complete long before diffusion at intensive margins and the relative contributions of changes in extensive and intensive margins to worldwide diffusion change over the diffusion process.

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[1] This work is based upon Pulkki-Brännström (2009), the Ph. D thesis of the first named author. Details of data used and any necessary interpolation undertaken to fill gaps are discussed further there and in the Appendix.

We next address how diffusion in one country (the intensive margin) may be affected by changes in use in other economies i.e. whether there are international spillovers. We argue that the larger part of the appropriate diffusion literature takes the view that diffusion patterns are the result of the adoption decisions of locally based production units and emphasises two main approaches: (i) epidemic hypotheses relating to information spreading and risk reduction; and (ii) decision theoretic arguments based on rank and/or stock effects impacting upon the profitability of adoption. We consider the simple extension of both approaches to allow for inter-country spillover effects. In the former approach however the spillover effects will be positive, in the latter probably negative.

The HCCTAD provides good data on the diffusion of particular technologies in different countries that enable an empirical approach to the spillover issue. The empirical work herein considers two technologies that have partly been chosen on the grounds of data availability but also selected because there is a history of their prior study. The first study addresses the switch from sail to steam (see Harley, 1971) over the period from 1809 - 1938[2]. To this example we apply an epidemic model of diffusion. We find some limited evidence in favour of positive international spillovers. The second technology is the basic oxygen process in steel making (see Oster, 1982) where the data coverage is from 1952 - 1992. With this example we are able to illustrate both rank effects and most importantly some negative international spillover effects. This suggests that as diffusion proceeds and usage extends more widely in the world so the returns to later adopters are reduced and this delays their date of adoption. The paper closes by drawing conclusions.

2. Intensive and extensive margins

We define two diffusion margins: the extensive, referring to the spreading of first use across economies; and the intensive, referring to the intensity of use within

[2] We are of course very aware of the connections with Nick Von Tunzelmann's ground breaking first major work on the use of steam power in Britain, Von Tunzelmann (1978). There is also a very informative recent update in which he was involved, Nuvolari et al. (2011).

economies post first use. Usage of new technology can be measured in a number of ways, three of which are most common: (i) absolute total usage or ownership at a given point in time; (ii) usage or ownership relative to some total output measure, e.g. Gross Domestic Product; and (iii) total usage relative to some estimated post-diffusion (asymptotic or saturation) level of usage. Here we concentrate upon the first, and use D_{it} to represent the extent of use of a new technology within country i in time t.

A measure of inter-country diffusion is the number of countries that are using the new technology at a level D_{it} in excess of some externally chosen base level D^*. We represent this number in time t by z_t. The most obvious choice for D^* is zero; however a positive number makes the analysis less sensitive to differences across countries in the accuracy of reporting early data. The extent of use across all countries (the world) is the sum of D_{it} over the z_t using countries, which we write as D_t. By definition (1) must hold

$$D_t = z_t * (D_t / z_t) \tag{1}$$

indicating that the overall worldwide level of use of the new technology derives from two multiplicative indicators reflecting: (i) the number of using countries, z_t - the extensive margin; and (ii) the average intensity of use in each country, D_t / z_t - the intensive margin.

We may express (1) as a relationship between growth rates rather than levels by taking natural logarithms and differentiating with respect to time. Denoting $w_t = D_t / z_t$, in discrete time (using Δ to represent a difference between time t and time $t - 1$) the decomposition is

$$\Delta lnD_t = \Delta lnz_t + \Delta lnw_t. \tag{2}$$

Equation (2) then allows a decomposition of the actual growth in overall diffusion into contributions from growth in inter- and intra-country diffusion respectively.

The power of this simple decomposition method can be illustrated using the diffusion of mail services as an example. The sample is 15 OECD countries over the period

1850-1990[3]. Use is measured by units of mail handled. A country is defined as having adopted the technology of postal services when the units of mail handled per year exceed 10 million (we have also further experimented with different values for *D**). This choice for *D** balances the need to distinguish users from non-users, while avoiding situations where no changes in inter-country diffusion would be detected. There was a considerable increase in overall diffusion over the period from 812 million units handled in 1850 in the 8 countries that were users in 1850 to 82,950 million units in the 15 countries that were users in 1990. Figure A1 in the Appendix illustrates this worldwide diffusion of mail services[4] as well as (representative) patterns for two countries, the US and Japan for the period from 1870 - 1990. We find that, in general, both the patterns of use across countries and the pattern of use within countries follow the traditional S-shaped curves.

We have decomposed the growth in overall diffusion in the sample countries over the period 1850-1990 as a whole, and find that growth in overall diffusion decomposes such that 14% was due to an increase in inter-country diffusion (increase in the number of using countries) and 86% was due to higher intra-country diffusion (increase in average usage). If *D** is set at a higher value, say 50 million, a larger number of countries were non-users in 1850 and we have that 36% of growth in overall diffusion is attributed to inter-country diffusion and 64% to intra-country diffusion. This example suggests, not surprisingly, that in the long run, overall diffusion is primarily driven by an increasing intensity of usage within using countries.

More insight can be gained by examining the relative contributions of the two margins on overall growth within each decade. The data is presented in Table 1 Panel A. We allow the total number of countries in the sample to vary across decades (but not within each decade). This allows those countries to be included in the sample where first observed usage is at such a high level that the country cannot be considered a non-user prior to that date. We exclude these countries from the analysis in decades

[3] The (second world war) years 1938-1950 are omitted because of several missing values and wide volatility. Other missing values are imputed where necessary using the closest observed values or linear interpolation where several consecutive values are missing, See the Appendix.

[4] Excluding both world war periods.

before first observed usage. Such an approach is valid because our concern is with *changes* in overall, inter- and intra-country diffusion over a given time period, and because we are interested in the relative (rather than absolute) contributions of inter- and intra-country diffusion to changes in overall diffusion.

With D^* set equal to 10 million, overall diffusion and average usage increased continuously throughout the period 1830-1990. However, growth in overall diffusion tended to be smaller in the second half of the observation period. After the initial decade(s) in which the number of users was constant (1830 – 1850), changes in inter-country diffusion accounted for over 40 per cent of overall diffusion. As diffusion (and time) proceeded, changes in intra-country diffusion began to dominate the overall growth process and in fact there were no increases in inter-country diffusion after 1890. When D^* is set equal to 50 million a similar pattern is observed (Table 1 Panel B) but in this case the extensive margin was still expanding up until 1920. This is illustrated in Figure 1 where we plot the last two columns of Panel B. Here, the declining importance of inter-country diffusion is especially evident after the decade 1850 – 1860 when 94 per cent of overall growth had been due to an increase in the number of users.

Similar results can also be obtained using alternative measures of overall diffusion and different technologies. We examined the diffusion of telephones, electricity and the basic oxygen steel-making process using both absolute and relative measures of diffusion. The common pattern that emerges is that growth in the extensive margin drives changes in overall diffusion in the first decades of the international diffusion process but after that it is the increasing intensity of usage by existing users that dominates.

The above is only an accounting exercise and so provides no information upon the forces that drive diffusion. We consider, however, that a crucial issue of prime importance in understanding the overall diffusion process is how the use or diffusion of a new technology in one country is affected by the use or diffusion of that technology in other countries. This is a question that has rarely been asked in the large body of literature that has studied domestic diffusion processes. If there are such international spillovers then domestic diffusion cannot be satisfactorily analysed in isolation from the diffusion processes that are taking place in other countries. Although there is the potential to study the spread of first use across countries (the extensive margin), we explore the issue of spillovers further below by concentrating almost exclusively upon the determinants of use in individual countries i.e. the intensive margin.

3. International spillover effects

In this section conceptually we address how diffusion in one country may be affected by (changes) in use in other economies i.e. whether there may be international spillover effects. The foundation of our approach is to concentrate upon the adoption decisions of individual local production units assuming that such production units are autonomous decision makers. We expect their behaviour to be conditioned by both the local and global markets in which they are located. Although it is possible that some production units may be subsidiaries of transnational corporations and thus in reality their decisions may reflect the strategy of the transnational rather than local factors, for the technologies and the time periods we are exploring here, this is unlikely to be a major consideration.

The relevant diffusion literature that this gives rise to is then largely built upon two approaches: (i) epidemic hypotheses relating to information spreading and risk reduction; and (ii) decision-theoretic arguments based on rank and/or stock effects impacting upon the profitability of adoption. These two approaches define two particular types of spillover mechanisms.

In the information based approach, international spillovers could arise as non using production units in one country may gain knowledge about a new technology by observing or interacting with using units in other countries (as well as their own). There is a considerable literature on the geography of innovation (e.g. Audretsch and Feldman, 2003; Feldman and Kogler, 2010) that further argues that such spillovers will be closely related to distance in that spillovers are more likely from closer rather than distant countries. Although most of this work relates to patenting, innovation or technology generation rather than diffusion the logic could be extended to the diffusion process. In the current context this might suggest in the information spreading case there would be greater knowledge spillovers from neighbouring countries than more distant countries.

In decision theoretic models it is usually assumed that there are no knowledge deficiencies and thus informational spillovers are irrelevant. Instead it is argued that firms operate in a world product market and adoption continues to the point where the gross returns to the marginal adopter equal the cost of adoption. In such a world the spillover effects would be pecuniary, in that, for example, usage of a new technology by a competitive rival located in another country may drive down (world) product price and deter adoption by a domestic production unit. It is less simple to argue that such pecuniary spillovers will depend upon distance if firms are truly operating in a world market.

One may note that, although informational effects may create a positive relationship between the international extent of use and further domestic use, possible pecuniary effects are more likely to predict a negative relationship between extent of use elsewhere and domestic diffusion. In the following sub sections we put some flesh on these bones.

3.1 Epidemic hypotheses

Two classic epidemic models of diffusion are Bass (1969) and Mansfield (1961). Bass (1969) argued that potential adopters partly learn about the new technology from those who have already adopted it[5]. When the number of users is small, opportunities to learn are few, but as the number of users increases the flow of information also increases. According to Bass, this spreading of information is the driving force behind extensions in diffusion.

[5] Although the model is most frequently discussed in terms of number of users (inter-firm diffusion), the depth of use by each user (intra firm diffusion) could also be incorporated.

Mansfield (1961) developed a model in which uncertainty about the returns to adoption discourages diffusion. As more information about the technology is obtained, uncertainty about the profitability of the new technology is reduced which encourages further use. Two economic variables, profitability and cost of adoption, determine diffusion speed. Thus in both the Bass and Mansfield models, information spreading is of key importance in diffusion.

Generally however, when employed, these models do not allow for information spreading across national boundaries, but both models can be extended to incorporate international spillovers by including foreign users as a source of information for domestic potential users. Denoting domestic extent of use (of a given technology) in country i by S_{it} and international usage by W_t, in an epidemic learning model with international spillovers the extent of use in country *i* at time *t* is then modelled as evolving according to

$$dS_{it} = \left(g + b\frac{S_{it}}{S_{it}^{*}} + a\,\frac{W_t - S_{it}}{W_t^{*} - S_{it}^{*}} \right)\left(S_{it}^{*} - S_{it} \right) \tag{3}$$

where W^*_t and S^*_{it} represent the potential or post diffusion levels of use for international and domestic diffusion respectively. This model is a disequilibrium model in the sense that during the diffusion process usage is assumed to be less than, but approaching towards the potential level, over time. Extensions of (domestic) use in this approach are driven by the discrepancy between current usage and the potential level ($S^*_{it} - S_{it}$) on the one hand and by information spreading on the other hand. Those who have not yet adopted obtain information from current domestic users (represented by the ratio S_{it}/S^*_{it}) and current users in other countries (captured by $(W_t - S_{it})/(W^*_t - S^*_{it})$). The parameter γ is traditionally interpreted as the influence of information flows from sources other than current users (such as advertising) and is expected to be positive (although assumed to equal zero in the Bass model). The parameters β and α measure the effects of domestic and foreign users respectively on domestic diffusion. If international use has no domestic impact then $\alpha = 0$ (as assumed in the Bass and Mansfield models usually employed) but we expect both β and α to be positive because as long as the technology is superior to alternatives, information will have an inherently positive effect on the extent of use, whether the source of that information is foreign or domestic.

As discussed above, it may be the case that information spreads more easily between economies that are closer neighbours. If this were so then a more disaggregated approach might be more appropriate in which information is allowed to spread via pairwise country links rather than via the aggregate term W_t. We have considered this alternative and also undertaken some preliminary analysis, but what is really required to pursue this route in the sail/steam example we consider below is detailed data on pairwise technology use and trade patterns between countries. This we do not have. We thus explore the aggregate model at this time.

This model detailed here may be compared to work by Kumar and Krishnan (2002) who argue that diffusion in one country is likely to affect another country's diffusion through both of the parameters γ and β. Influence through γ implies that potential adopters get exposed to diffusion as they meet people through travel, read industry publications or newspapers, or see advertisements all of which give information crucial for adoption. Kumar and Krishnan interpret an international effect that comes through β instead as indicating that "the degree to which a potential adopter would place faith on the internally generated information will be affected by what happens in other countries" (Kumar and Krishnan, 2002:321). In the historical case to which we apply our model, modelling spillovers through the β-parameter would in our view require modelling how the segment of the market in which the source of information operates affects the value of that information for the potential adopter.[6] In contrast having an additive decomposition of the γ-effect, as we do here, implies the simple and intuitive argument that potential adopters have good access to information from other countries.

In section 4 below we estimate the model represented by equation (3) using data upon the switch from sail to steam in order to explore whether this model adequately

[6] The international shipping market was to some extent segregated by length of journey and type of cargo to the effect that the steamship was first competitive on short-haul journeys and perishable goods while on long-haul routes the sailing ship remained competitive for longer.

summarises the data and, if it does so, whether there is evidence of international knowledge and thus diffusion spillovers.

3.2 Decision theoretic approaches

An alternative way of modelling international spillovers is through consideration of a competition effect such as the stock effect within a decision theoretic modelling framework. The stock effect is a negative relationship between the profitability of adoption and the number of other firms in the market who have adopted the technology at that time[7] (Karshenas and Stoneman, 1993). We propose that international spillovers can be modelled by applying a model such as the Cournot model of Reinganum (1981) or the monopolistic competition model of Götz (1999) to an open economy setting in which firms operate in (sell on to) an international market in which the profitability of adoption depends on the extent of international diffusion.

Suppose that diffusion is a switching process through which users of an existing process technology switch to a new, lower cost production method. Each potential adopter *j* in country *i* switches at a time that is individually optimal (profit-maximising) for it. We assume that adoption increases per-period profit from production by an amount in each period denoted by[8] $\delta\pi_{ijt}$, which depends on the characteristics of the technology on the one hand, and on market structure and firm-specific factors on the other hand. Of key interest to us is the precise relationship between $\delta\pi_{ijt}$ and the extent of use by other firms in the world market including firms outside the domestic economy. In the tradition of Reinganum (1981) and Götz (1999), as the extent of diffusion increases and a greater proportion of firms use the new technology, so producers adjust their optimal output/pricing decisions. The result of these adjustments is that per-period profits of both adopters and non-adopters fall, and the

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[7] We have also considered order effects (Fudenberg and Tirole, 1985) but do not report on them here.
[8] $\delta\pi_{ijt}$ is precisely defined as the difference in profit of firm *j* in country *i* between period *t* using the new technology and period t-1 using the old technology.

gain from switching technology, $\delta\pi_{ijt}$, also falls, giving rise to the stock effect.[9] We assume that the market is efficient with limited transaction costs such that any such pecuniary spillovers do not differ according to distance from their source.

The optimal date of adoption for the firm depends not only on $\delta\pi_{ijt}$ but also on the possible benefits of deferring adoption. One such benefit is any expected fall in the cost of adoption over time, and another is the opportunity cost of adopting today, which relates to alternative uses of the resources required for adoption. Denoting the cost of adoption by K_{it} and the discount rate by r, the benefit (reduced adoption cost) of postponing adoption at time t is $rK_{it} - \Delta K_{it}$ where ΔK_{it} is the expected increase in K_{it} in the interval $(t, t+1)$. The optimal adoption date for each producer is the time at which the costs and benefits of postponing adoption are equal, $\delta\pi_{ijt} = rK_{it} - \Delta K_{it}$. This is called the arbitrage condition in the literature. This condition makes it clear that, ceteris paribus, as the cost of adopting the new technology K_{it} falls over time so more firms will adopt the new technology although expectations of such declines will delay diffusion. We may note that such reductions in the costs of adoption may come about as the result of improvements in the production of the new technology and/or the inter-temporal pricing strategies of the suppliers of the new technology (e.g. Ireland and Stoneman, 1986). It is also worth observing that if there are improvements over time in the technology being replaced (see e.g. Harley, 1971) this will reduce $\delta\pi_{ijt}$ and tend to slow diffusion.

On an aggregate level, determinants of the extent of use in a given country depend on the optimal adoption dates of all producers within that country. To discuss this further, we find it useful to separate $\delta\pi_{ijt}$ in to two parts, $\delta\pi_{it}$ which is country specific and u_{ijt} which represents producer-specific costs and benefits of adopting or postponing adoption, such that $\delta\pi_{ijt} = \delta\pi_{it} + u_{ijt}$. Then the optimal adoption date for producer j located in country i is given by the condition that $\delta\pi_{it} + u_{ijt} - rK_{it} + \Delta K_{it} = 0$. It is then clear from this reasoning that differences in the extent of use across

[9] Götz (1999) argues that his model has a positive stock effect because the extent of use increases with time. However, this relationship is in fact due to the falling cost of adoption over time. The relationship between current and future use (the stock effect as commonly defined) is also negative in Götz's model.

countries can be attributed to firm heterogeneity within countries on the one hand (u_{ijt}) and cross-country differences in the profitability ($\delta\pi_{it}$) and opportunity cost of adoption (rK_{it} - ΔK_{it}) on the other hand.

An empirical model of diffusion based on the arguments we have just outlined is necessarily specific to a set of assumptions about market structure, firm heterogeneity etc. As a first test of the hypothesis of a negative international stock effect, we propose estimating a simple linear model in which the model variables are based generally on the arguments of the arbitrage condition. The empirical example we use is from crude steel production, namely the switch from the open hearth furnace to the basic oxygen furnace (BOF) between 1953 and 1985. The empirical analysis is reported in the next section following on the analysis of the switch from sail to steam using the epidemic framework.

4. Empirical evidence

4.1 From sail to steam

We first apply the epidemic model of diffusion to the switch from sailing ships to steamships over the period 1809 - 1938. Diffusion is measured by the tonnage of ships that are either steam- or motor ships; although motor ships did not start to diffuse until towards the end of the study period, our data source does not distinguish between the two categories. We use annual data for 15 OECD countries. For each country we only analyse use post first use (the intensive margin). The data coverage is very good; in particular, early observations are only missing for two countries (Canada and Italy) and therefore our measure of international diffusion covers 13 countries over the whole study period. The world proportion of steam- and motor ships in total tonnage W_t /TW_t (obtained by aggregation) has the typical S-shape when plotted over time (see Figure A2 in the Appendix). For presentational reasons we are unable to illustrate patterns for individual countries.

Before the model can be estimated we need to make some assumptions about levels of potential use, S^*_{it} and W^*_t. Some studies model S^*_{it} as a function of other variables, for example the prices of output and adoption (Knudson, 1991)[10]. Given the data available to us, we make the simple assumption that the population of potential adopters is given by total tonnage at each point in time denoted T_{it} and TW_t for country *i* and the world respectively. Essentially this assumption says that the potential adoption level is 100 per cent of total tonnage in each country throughout the diffusion period.

Dividing both sides of (3) by T_{it} and imposing the assumptions $S^*_{it} = T_{it}$ and $W^*_t = TW_t$ we obtain the discrete-time estimating equation

$$\frac{S_{i,t} - S_{i,t-1}}{T_{i,t-1}} = \left(\gamma + \beta \frac{S_{i,t-1}}{T_{i,t-1}} + \alpha \frac{W_{t-1} - S_{i,t-1}}{TW_{t-1} - T_{i,t-1}} \right) \left(1 - \frac{S_{i,t-1}}{T_{i,t-1}} \right) + \varepsilon_{i,t} \tag{4}$$

where $\varepsilon_{i,t} \sim N(0,\sigma^2)$.

Estimation simply requires tonnage data for each country (see the Appendix). We obtain estimates for each country separately, initially using ordinary least squares and heteroskedasticity-consistent standard errors (where relevant). For some, but not all, the residuals were serially correlated and in these cases (indicated by [1] after the country name) the results reported below refer to FGLS (Feasible Generalized Least Squares) estimates where in the first step the (first-order) autocorrelation coefficient was estimated and in the second step the model was transformed using this estimate. We estimated the model up to 1938 for all countries, however, as the diffusion process was completed earlier in many countries, and there are some concerns about data quality (including several consecutive missing observations in some cases) over the years between 1917 and 1938, we report here estimates for a shorter period when this appears most appropriate.

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[10] Knudson's (1991) approach suggests an alternative to the way we proceed here, namely that S^*_{it} could be modeled as a function of W_t. Although Knudson treats prices as exogenous to diffusion, our model would require endogenising the price of shipping services by explicitly modeling the supply of shipping. We have not explored this option further but modeling the link between international and domestic diffusion in this way is an interesting option for future research.

Using measures of model fit, namely maximised log likelihood and residual sum of squares, we have chosen for each country the model which appears to best fit the data; this is either the full model or a restricted version either imposing no international spillovers ($\alpha=0$) and/or no exogenous effects ($\gamma=0$). Where model fit varied very little across specifications we present here results of the most parsimonious model - the standard Mansfield model which has only one non zero parameter (β). This led us to choose a model incorporating international spillovers as a significant determinant of domestic diffusion for five of the countries in our sample (Austria, Belgium, Finland, Italy and the US). The results for these five countries are presented in Table 2. Estimates of the international effect, α, vary between -0.46 and +0.91. However, for Austria and Italy the estimate of α is negative and as negative information spillovers make little sense, if any, this tends to suggest that the model being tested is not appropriate for these two countries. We also find that in general all the estimated models fit poorly to the Belgian data – probably because a high level of use was attained early on (90% in 1881). This leaves only Finland and the United States as valid examples illustrating positive estimated international spillovers. However for Finland and the United States the point estimates of β are negative which suggests that the model is also inappropriate in these cases.

As an alternative take upon the data, we also report in Table 2 (columns 8 and 9) the results of fitting the standard Bass and Mansfield models to total worldwide diffusion (W_t/TW_t) over the period 1838-1913. Bass exogenous effects (represented by γ) are significant, but with an unexpected negative sign, which would indicate the influence of external factors that slow down the process of diffusion. The 95 per cent confidence interval for β is (0.09, 0.16) (upper limit 0.14 in the Mansfield model) and this can be considered a benchmark for the individual country results. However, the point estimates of β from the full model (Table 2) vary from -0.38 to +0.56 and none are within the benchmark interval: they are either negative or show large positive values. Again this indicates that the epidemic model may not be appropriate.

In Table 3 we compare results between a model with no international spillovers and a model with only international spillovers for three countries where the two perform equally well: Australia, New Zealand and United Kingdom. All estimates of α and β

are positive, and significantly differ from zero. The estimates of *β* differ little from the estimates of *α*, the international spillover coefficient, which might suggest that informational spillover effects may play a role in the diffusion process, but the data cannot distinguish between domestic orientated and international orientated models and either can be valid. It should however be noted that both models fit poorly for Australia and New Zealand; perhaps because early observations are missing (the first observations are 18% and 22% in 1876 and 1870 respectively).

Results for the United States and the United Kingdom merit a separate examination, as they were major suppliers (Harley, 1973) as well as major users of ships. Our data shows that the combined share of the two countries in the world stock of ships (either W_t or TW_t) was never under 60 percent during the period 1837 to 1938. Harley (1973) presents some interesting data on the supply-side. Metal was increasingly adopted as the material for sailing ship construction during the second half of the 19th century, and Harley (1973) argues that the advantage that the United Kingdom had in metal shipbuilding led to a shift in world shipbuilding activity away from the United States to the United Kingdom[11]. On the demand-side, the United States also fell behind the United Kingdom in terms of both total and steam and motor tonnage; in our data, the United Kingdom has the largest tonnage between 1870 and 1919.

Our results indicate that international spillovers were not significant for steamship diffusion in the United Kingdom when domestic spillovers are allowed, whereas for the United States (see Table 2), extensions of use appear driven by international spillovers, although there is a surprising negative coefficient on past domestic use (*β*). However, the "international only" model (Table 3) is as good a predictor of current usage as the "domestic only" model in both the United Kingdom and the United States. We also find that in the United States, international spillovers are estimated to be weaker if we include data from the period before 1837 (Table 2; *α* estimate falls from +0.23 to +0.14) when the only other user of steamships was the

[11] Harley (1973) also explores an epidemic model in seeking to explain cyclical variation in shipbuilding output. He finds that the model is not appropriate. A major difference between our approach and that of Harley is essentially that here the epidemic model is applied to the stock of ships while Harley looks at new purchases only.

United Kingdom. These results may indicate that after its early lead, the United States was relatively slow in adopting steamships.

Results for the other seven countries, in which there was no evidence of international spillovers (nor Bass exogenous effects) in our data is provided in Table 4. Two estimates of β are significantly below the benchmark (0.05), however none is negative or above the benchmark. These estimates are rather accurate, and the fit of the model is relatively good. However, all estimates suffered from first-order serial correlation (adjusted for using FGLS[12]), and France and Germany also suffered from higher order serial correlation in the period extending beyond 1914 (results not shown).

Overall, these epidemic model estimates provide some limited evidence in favour of positive international (informational) spillovers. Such spillovers may therefore have been an influence on the diffusion of steamships that to date has largely been ignored. However, in several cases the model is a poor fit. Also some results indicate negative informational spillovers (domestic or international) which throws doubt on the appropriateness of the model in some circumstances. This may, to some extent, indicate the limitations of applying a single model to a sample that encompasses a wide range of countries within which the diffusion process occurred with different speeds and at different points in time over a very long period span of years.

4.2 The basic oxygen furnace

Our second empirical exercise, using the stock effects approach, concerns the diffusion of the basic oxygen process (BOF) for making crude steel over the period from 1952 - 1985. We measure (as detailed in the Appendix) use of BOF by the proportion of all crude steel producing capacity (except steel produced using the electric arc furnace) that incorporates BOF, which for any individual country is a measure reflecting the intensive margin. This measure was also used by Oster (1982) in her study of BOF diffusion. The world capacity using the previous open

[12] No adjustment was made for Norway, because of higher order serial correlation.

hearth technology, capacity incorporating the basic oxygen process, and the basic oxygen proportion of total capacity, $W_t\ /TW_t$ (obtained by aggregation), are plotted over time in Figure A3 in the Appendix. The standard S-shape is revealed at this world level. Similar patterns can also be seen at the individual country level.

Building upon the argument above that the optimal adoption date for producer *j* located in country *i* is given by the condition that $\delta\pi_{it} + u_{ijt} - rK_{it} + \Delta K_{it} = 0$, the cross country panel data estimating model employed is

$$\begin{aligned}\left(S/T\right)_{it} = \alpha_1\left(S/T\right)_{it-1} + \alpha_2\left(W/TW\right)_{-i,t-1} + \beta_1 r_{it} + \beta_2 n_{it} + \beta_3 e_{it} \\ + \gamma_1 K_t + \gamma_2 \Delta K_t + \gamma_3 t + \eta_i + \varepsilon_{it}\end{aligned} \tag{5}$$

where $S_{i,t}$ and $W_{-i,t}$ denote the tonnage of crude steel produced using BOF in country *i* and in other countries respectively, and T_{it} and $TW_{-i,t}$ denote total tonnage produced in country *i* and in other countries respectively.

We have divided the stock effect (the impact of home and overseas use of the new technology on $\delta\pi_{it}$) into its domestic and international components because the lagged domestic extent of use, $(S/T)_{it-1}$, is expected to pick up effects not captured by other variables in the model. Although both α_1 and α_2 are expected to be negative under the stock effect hypothesis, our focus is on the international effect α_2.

As we were unable to locate data upon the cost of acquisition of the basic oxygen furnace we have employed three time control terms *t*, K_t, and ΔK_t, the first of which refers simply to time (year), K_t being an arbitrary non-linear function of time equal to $2^{-0.1t}$, and ΔK_t being the annual change in this function. The three terms are included as proxies for the price and changes in the price of adoption following Colombo and Mosconi (1995) who argue that a variable that indicates the passage of time reflects changes in the price of adoption unless that is not captured by any other variable in the model[13]. The convexity of the function K_t is a reasonable assumption as it implies

[13] This approach of course implies that costs of adoption are considered exogenous rather than endogenous, the latter being a possibility we cannot explore further. In the case of the BOF it is interesting to note that the Austrian inventors of BOF mishandled licensing agreements and patent rights and thus seem to have "given away [the] technology virtually free of charge" (Tweraser, 2000, p. 313-4 footnote 74).

that postponing adoption by one period becomes less attractive over time, as the rate at which adoption cost falls slows down. We expect that $\gamma_1<0$ and $\gamma_2>0$ to reflect this. Convexity arises for example if there are economies of scale in the production of furnaces. We experimented with a number of functional forms and the function $K=k^{-\lambda t}$ with $k=2$ and $\lambda=0.1$ performed well in the sense that estimates of γ_1 and γ_2 were relatively robust even across different measures of extent of use. We also include the domestic exchange rate (in domestic currency per USD) denoted by $e_{it.}$ Although the exchange rate at the date of adoption may impact upon the cost of capital equipment, if imported, we primarily expect that e_{it} will affect the profitability of sales of steel in time t and thus impact positively on profitability.

Other variables are included in order to capture variation in the profitability and cost of adoption across countries and over time. The real interest rate is used as a measure of the discount rate. We use two variables, government bond yield (r_{it}) for the nominal interest rate, and annual percentage change in the consumer price index (n_{it}) as a measure of inflation. The overall effect of the real interest rate is expected to be negative because incentives to postpone adoption are greater when the opportunity cost of adoption (rK_{it}) is high. Thus we expect $\beta_1<0$ and $\beta_2>0$. We also include country specific effects, η_i, to represent any other country level effects.

The error term ε_{it} reflects the distribution of producer heterogeneity within the country (u_{ijt}) and unexpected shocks to either the cost or the benefit of postponing adoption which may both affect the optimal adoption date for all producers within a country.

The estimation method is least-squares dummy variables (LSDV) adjusted for first-order serial correlation. LSDV is appropriate given the dimensions of the data: relatively large T and small N, however we also present one-step GMM results as suggested by Judson and Owen (1999) for a similar country panel. We use heteroskedasticity-consistent standard errors, second to fourth lags of $(S/T)_{it}$ and $(W/TW)_{-i,t}$ as the GMM instruments, and forward orthogonal deviations (Arellano and Bover, 1995). The first difference transformation would also give similar results. 2-step GMM results suffer from considerably (over five times) higher standard errors.

The results are presented in Table 5 for the period 1960-1985. The extent of use elsewhere in the world ($W/TW)_{-i,t-1}$ is estimated to have a significant negative effect on the domestic BOF proportion: the point estimate is -0.135 (-0.127 using GMM) which suggests that a sample average annual increase in ($W/TW)_{-i,t-1}$ of three percentage points reduces the domestic BOF proportion by 0.40 percentage points, ceteris paribus (95% CI 0.03-0.78). The estimate is not robust to including pre-1960 data. This is likely due to the small value of ($W/TW)_{-i,t-1}$ (less than 0.04) before 1960 and that only 20 observations of S_{it} are non-zero before 1960. The country effects η_i, which reflect country-level determinants of diffusion not included elsewhere (e.g. the price and availability of scrap metal; see Maddala and Knight, 1967) are highly significant as expected. The nonlinear time control term K_t (and ΔK_t in the GMM equation) is statistically significant with the expected sign.

The results support our hypotheses regarding the time control terms which reflect changes over time in the cost of technology, with the real interest rate, included for a similar reason, also being significant as a determinant of diffusion (the chi-squared statistic for a joint test of significance for the nominal interest rate and inflation is 12.6). The exchange rate, included as a potential factor determining the profitability of adoption, is not however statistically significant.

As a robustness check, we investigated the possibility that the domestic BOF proportion is affected by increases in the demand for steel over time, which we proxy by (the log of) total real Gross Domestic Product in our sample of countries. We find that the variable is not statistically significant nor does its inclusion affect the estimates for variables other than K_t (which remains statistically significant with a negative sign). In particular, and despite the high degree of correlation (0.90) with ($W/TW)_{-i,t-1}$, the estimated international spillover effect is very similar in magnitude, although now only significant at 10% (coefficient estimate -0.123, standard error 0.068).

The main finding is that, in this example and with these methods, we can isolate negative international spillover effects.

5. Conclusion

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 total international diffusion in the early years of the diffusion process. In the later years it is the intensive margin 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. This exercise illustrates that diffusion at the extensive margin is complete long before diffusion at intensive margins; and that the relative contribution of changes in extensive and intensive margins to worldwide diffusion change over the diffusion process.

The link between international and domestic diffusion can be established using information spreading arguments or through competition based arguments in a decision theoretic approach. We have presented two theoretical models corresponding to these two traditions in the diffusion literature. Our models give rise to opposite hypotheses about the sign of the international spillover effect. If informational effects dominate, the relationship between use abroad and extensions of use at home is expected to be positive. In the decision theoretic approach, if the profitability of adoption falls with the extent of use by rivals, as in the Reinganum (1981) and Götz (1999) models, a negative international effect is expected. The decision theoretic approach also produces testable predictions about other determinants of diffusion.

The empirical work considers two technologies that have partly been chosen on the grounds of data availability but also selected because there is a history of their prior study. In each case we explore the spread of use in individual countries (the intensive margin) over time and the impact of usage elsewhere. The first study addresses the switch from sail to steam (see also Harley, 1971) over the period from 1809 - 1938. To this example we apply an epidemic model of diffusion. We find some limited evidence in favour of positive spillovers. The second technology is the basic oxygen process in steel-making (see also Oster, 1982) where the data coverage is from 1952 – 1992. With this example, using panel data techniques, we were able to illustrate that there are negative spillover effects, which suggests that the spread of diffusion worldwide outside the domestic economy reduces the returns to later adopters in the domestic economy and delays their dates of adoption. We also found that in the diffusion of BOF a significant role was played by the real interest rate, the cost of acquiring new technology and changes therein; the exchange rate did not have any significant impact.

One potential area for future research on international diffusion patterns is suggested by possible parallels with literature that argues that country specific factors such as schooling and political stability are important to the growth process (e.g. Caselli and Coleman II, 2001; Huntington, 1968; Przeworski et al., 2000). To date it has not been common in the diffusion literature to consider such factors. We investigated whether the case of BOF diffusion could offer empirical support for such suggestions. However the variables we used (average years of schooling from de la Fuente and Domenech, 2001, and the 5-year average annual number of assassinations and revolutions per one million population from Barro and Lee, 2000, originally from Banks, 1979) were not statistically significant, and so in this case there was no evidence in support of the hypothesis that the wider economic and political environment in which the firm operates affects production and adoption costs. Further investigation may prove more fruitful.

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Figures

Figure 1: Decomposition of changes in overall diffusion

D=50 m units of mail handled*

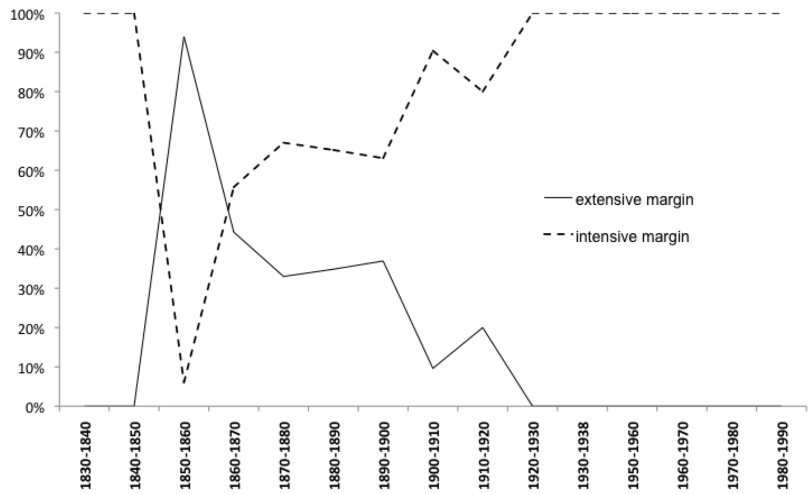


Figure A1. Diffusion of postal services (all and example countries)

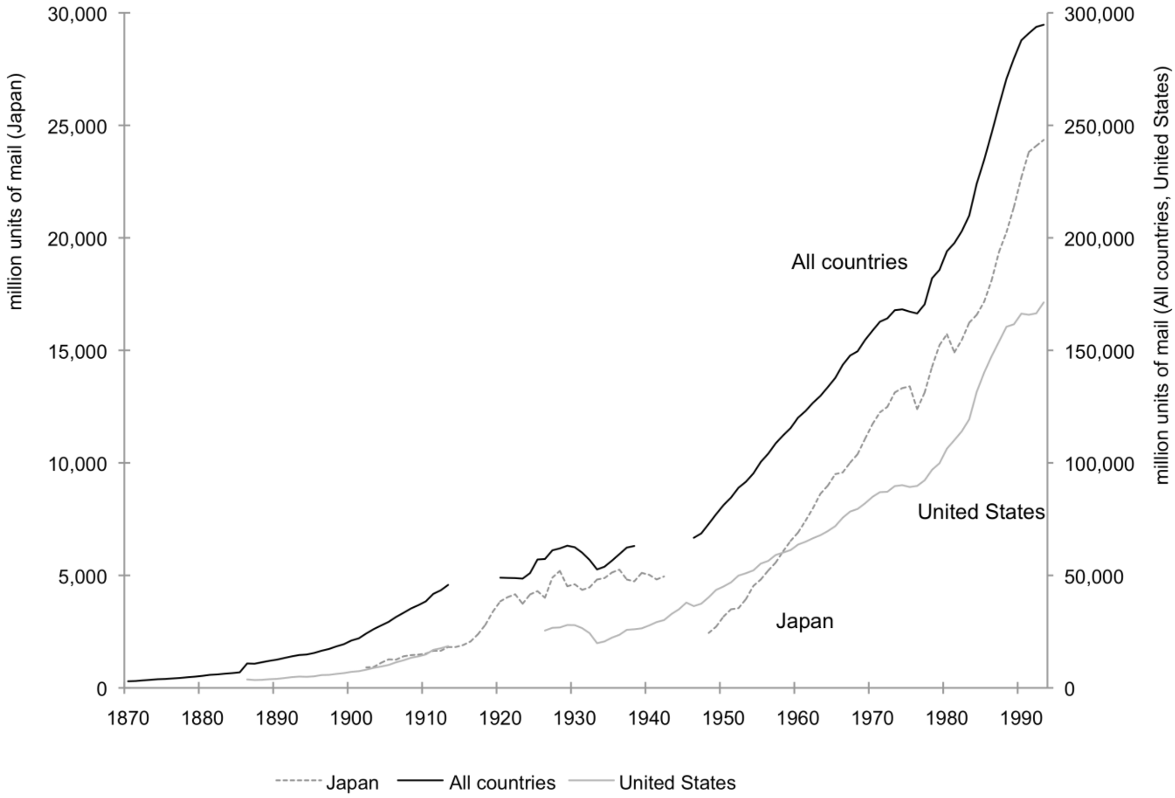


Figure A2. World diffusion of steam- and motor ships

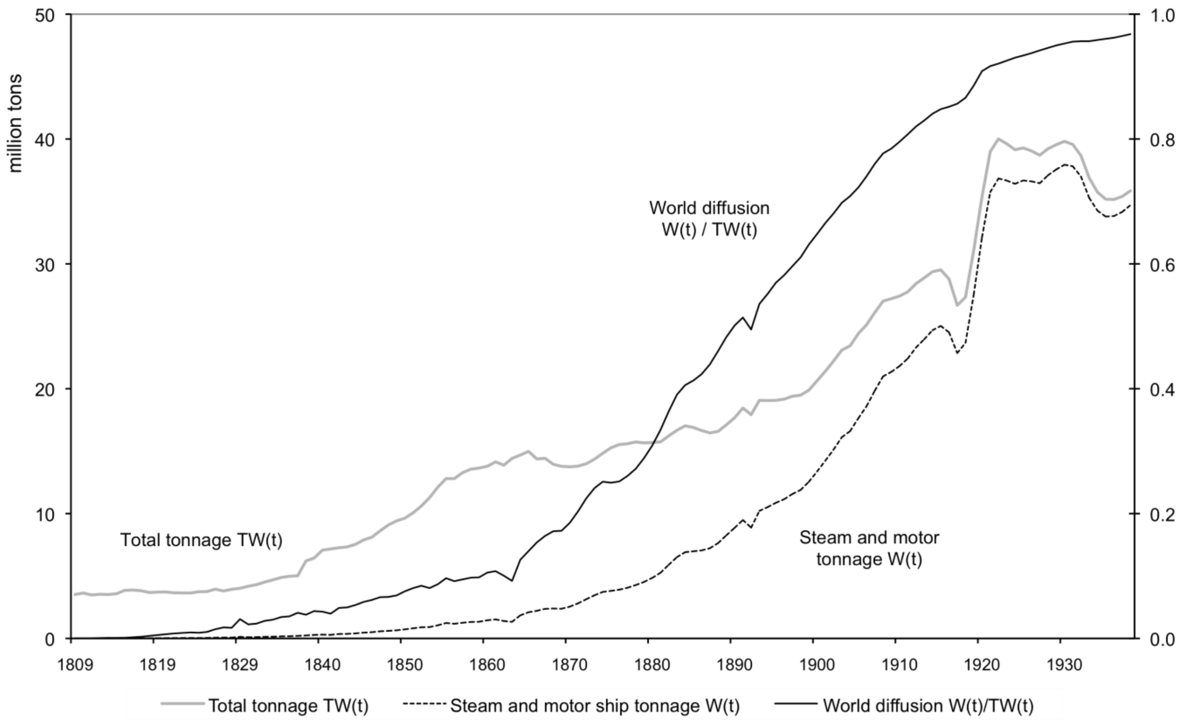
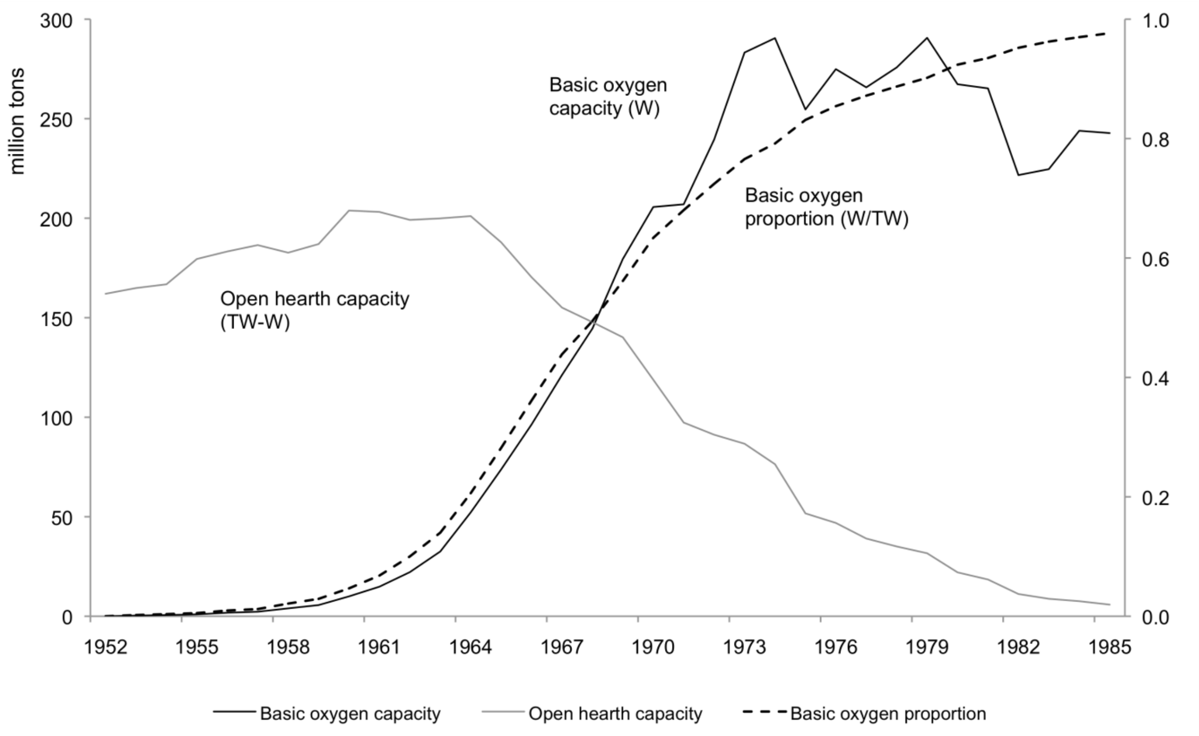


Figure A3. World diffusion of the basic oxygen furnace



Tables

Table 1: Changes in overall diffusion D_t, inter-country diffusion z_t and intra-country diffusion w_t

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

Time period	Sample size	Overall level of diffusion (million units)		Level of diffusion inter-country (users)		intra-country (million units)		Growth of overall diffusion	Shares of growth inter-country	intra-country
									$\Delta log\ z(t)$	**$\Delta log\ w(t)$**
	N	**D_t**	**D_{t+10}**	**z_t**	**z_{t+10}**	**w_t**	**w_{t+10}**	**$\Delta log\ D_t$**	**$/\Delta log\ D(t)$**	**$/\Delta log\ D(t)$**
1830-1840	10	127	182	2	2	64	91	0.36	0	1
1840-1850	11	353	668	3	4	118	167	0.64	0.45	0.55
1850-1860	15	812	1,585	8	9	102	176	0.67	0.18	0.82
1860-1870	16	1,693	2,892	10	12	169	241	0.54	0.34	0.66
1870-1880	17	2,917	5,311	13	15	224	354	0.60	0.24	0.76
1880-1890	18	5,339	8,563	16	18	334	476	0.47	0.25	0.75
1890-1900	19	12,568	21,056	19	19	661	1,108	0.52	0	1
1900-1910	20	21,967	38,493	20	20	1,098	1,925	0.56	0	1
1910-1920	20	38,493	49,717	20	20	1,925	2,486	0.26	0	1
1920-1930	20	49,172	62,515	20	20	2,459	3,126	0.24	0	1
1930-1938	20	62,515	64,012	20	20	3,126	3,201	0.02	0	1
1950-1960	21	81,268	120,088	21	21	3,870	5,718	0.39	0	1
1960-1970	21	120,088	158,748	21	21	5,718	7,559	0.28	0	1
1970-1980	21	158,748	194,042	21	21	7,559	9,240	0.20	0	1
1980-1990	20	187,875	281,637	20	20	9,394	14,082	0.40	0	1

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

Time period	Sample size	Overall level of diffusion (million units)		Level of diffusion inter-country (users)		intra-country (million units)		Growth of overall diffusion	Shares of growth inter-country $\Delta log\ z(t)$	intra-country $\Delta log\ w(t)$
	N	D_t	D_{t+10}	z_t	z_{t+10}	w_t	w_{t+10}	$\Delta log\ D_t$	$/\Delta log\ D(t)$	$/\Delta log\ D(t)$
1830-1840	14	115	163	1	1	115	163	0.35	0	1
1840-1850	16	334	632	2	2	167	316	0.64	0	1
1850-1860	17	718	1,500	3	6	239	250	0.74	0.94	0.06
1860-1870	18	1,608	2,836	7	9	230	315	0.57	0.44	0.56
1870-1880	18	2,836	5,211	9	11	315	474	0.61	0.33	0.67
1880-1890	18	5,211	8,417	11	13	474	647	0.48	0.35	0.65
1890-1900	19	12,422	21,017	14	17	887	1,236	0.53	0.37	0.63
1900-1910	20	21,928	38,462	18	19	1,218	2,024	0.56	0.10	0.90
1910-1920	20	38,462	49,717	19	20	2,024	2,486	0.26	0.20	0.80
1920-1930	20	49,172	62,515	20	20	2,459	3,126	0.24	0	1
1930-1938	20	62,515	64,012	20	20	3,126	3,201	0.02	0	1
1950-1960	21	81,268	120,088	21	21	3,870	5,718	0.39	0	1
1960-1970	21	120,088	158,748	21	21	5,718	7,559	0.28	0	1
1970-1980	21	158,748	194,042	21	21	7,559	9,240	0.20	0	1
1980-1990	20	187,875	281,637	20	20	9,394	14,082	0.40	0	1

Table 2: Steamships: countries with significant international spillovers

Country	**Austria**[1]	**Belgium**	**Finland**	**Italy**[2]	**US**	**US**	**World**	**World**
α	-0.458**	0.907**	0.130**	-0.037*	0.137**	0.234**	-	-
	(0.198)	(0.418)	(0.064)	(0.021)	(0.036)	(0.062)		
β	0.558**	0.272	-0.375*	0.202**	-0.056*	-0.196**	0.126**	0.111**
	(0.210)	(0.258)	(0.208)	(0.054)	(0.034)	(0.081)	(0.018)	(0.012)
γ	0.016**	-0.086**	-0.023*	-	0.006**	0.024**	-0.005**	-
	(0.008)	(0.036)	(0.012)		(0.002)	(0.010)	(0.002)	
N	74	94	40	51	104	76	76	76
RSS	0.038	0.731	0.0027	0.0149	0.024	0.023	0.015	0.015
log L	175.0	94.9	135.3	135.2	287.1	200.9	216.7	215.6
Period	1839-1912	1838-1931	1874-1913	1863-1913	1810-1913	1838-1913	1838-1913	1838-1913

Notes to Table 2. [1]FGLS estimates. [2]Spillovers are measured by W_{t-1}/TW_{t-1} not $(W_{t-1}-S_{i,t-1})/(TW_{t-1}-T_{i,t-1})$ because Italy is not included in W_t or TW_t. * significant at ten per cent, ** significant at five per cent.

Table 3: Steamships: domestic vs. international spillovers

Country	**Australia**	**Australia**	**N Zealand**	**N Zealand**	**UK**	**UK**	**US**[1]	**US**
α	-	0.137**	-	0.160**	-	0.166**	-	0.095**
		(0.041)		(0.058)		(0.025)		(0.010)
β	0.156**	-	0.168**	-	0.128**	-	0.054**	
	(0.048)		(0.065)		(0.018)		(0.009)	
N	49	49	69	69	124	124	103	104
RSS	0.234	0.232	0.644	0.637	0.083	0.085	0.025	0.025
log L	61.4	61.6	63.3	63.7	277.4	275.7	282.6	285.3
Period	1877-1925	1877-1925	1871-1939	1871-1939	1816-1939	1816-1939	1811-1913	1810-1913

Note to Table 3. [1]FGLS estimates. ** significant at five per cent.

Table 4: Steamships: countries with no evidence of international spillovers

Country	**Canada**[1]	**Denmark**[1]	**France**[1]	**Germany**[1]	**N'lands**[1]	**Norway**	**Sweden**[1]
$\boldsymbol{\beta}$	0.049**	0.101**	0.048**	0.097**	0.054**	0.135**	0.081**
	(0.015)	(0.022)	(0.012)	(0.018)	(0.021)	(0.036)	(0.021)
N	46	68	74	62	66	72	73
RSS	0.0249	0.0264	0.025	0.019	0.039	0.139	0.055
log L	107.7	170.5	190.1	162.7	151.5	122.8	159.2
Period	1894-1939	1845-1913	1840-1913	1852-1913	1848-1913	1867-1938	1867-1939

Notes to Table 4. [1]FGLS estimates. * significant at ten per cent, ** significant at five per cent.

Table 5. Results of the model of BOF diffusion

	LSDV/WG		GMM	
$(S/T)_{i,t-1}$	0.819**	(0.043)	0.930**	(0.025)
$(W/TW)_{-i,t-1}$	-0.135**	(0.064)	-0.127**	(0.056)
interest rate	-0.076	(0.184)	0.051	(0.244)
inflation rate	0.230**	(0.088)	0.196	(0.110)
exchange rate	-0.0025	(0.0027)	-0.0031	(0.0041)
$K=2^{-0.1t}$	-0.905**	(0.223)	-0.71**	(0.207)
ΔK	-		0.051**	(0.015)
t	-0.0026	(0.0031)	-0.0051	(0.0046)
constant	-		-0.0028	(0.0079)
No. of observations	263		255	
AR(1)	0.97		-2.7**	
AR(2)	-0.32		-1.5	
Sargan test p-value	-		0.773	
equation st. error	0.032		0.035	

Notes to Table 5. Unbalanced panel of 14 countries over 1960-1985. The dependent variable $S/T_{i,t}$ is the BOF tonnage divided by total tonnage in country *i*. $W/TW_{-i,t-1}$ is this share in countries other than *i*. ** significant at five per cent.

7. **Appendix**

The appendix contains information on modifications made to the raw data from HCCTAD for this study, illustrative plots of the pattern of diffusion of each of the three technologies (Figures A1-A3), and a list of the countries included in each case (Table A4).

Where possible, we consulted the original sources used by HCCTAD to impute missing values. Remaining missing values were imputed using random numbers between the two closest observed values. If consecutive observations were missing, the random numbers were ordered if there was a clear trend (increasing or decreasing) in the available data. All imputed values used for the postal services example are detailed in Table A1. All imputations of more than two consecutive values for the dependent variable in the shipping example are listed in Table A2. In Table A3, we list imputations for steel output that were used for the international diffusion measure (but not for the dependent variable).

For the panel data model on the diffusion of the basic oxygen furnace, we also employed a smoothing process to the output data to create a modified measure of capacity. This was necessary because the theoretical model refers to capacity rather than output, however capacity data is not available (e.g. OECD: "The Iron and Steel Industry", various editions) at the required level of precision. The assumption was that annual fluctuations in demand affect output but not capacity, in particular the downward movements in basic oxygen output before 1974, and all upwards movements in open hearth output.

More precisely, for each year and each country, capacity is the maximum output between 1952 and that year until the observed output peak. Following the peak, open hearth capacity is simply current output, or the highest output observed in the future, whichever is larger. Basic oxygen capacity peaked in several countries before the end of the study period, and in those cases where output fell considerably, basic oxygen capacity is defined as open hearth capacity after its peak. This is the case with Belgium (peak in 1974; data until 1983 used in the estimation), France (1980;

1983), Germany (1974; 1983), Italy (1981; 1982), Japan (1973; 1978), Luxembourg (1979; used in the international diffusion measure only), Spain (1976; only values 1980-1985 were used in the panel), United States (1979; 1984).

Table A1. Imputations for postal service diffusion

Year	Country for which data was imputed (value used)
1850	Australia (1851)
1860	Denmark (1861), Italy (1861)
1870	Norway (1868/1872)
1880	Spain (1881)
1890	-
1900	Greece (1899/1901), Japan (1902)
1910	-
1920	Austria (1922), Portugal (1919/1921), United States (1923). Also Canada (1915) and Ireland (1924) are used to compare changes in 1910-20 and 1920-30 respectively.
1930	Ireland (1929/1931)
1938	Austria (1936), Ireland (1937/1939), Spain (1935)
1950	-
1960	Ireland (1961)
1970	-
1980	Canada (1979)
1990	Netherlands (1989)

Table A2. Imputations for steam- and motor ship diffusion country time series

Country	Imputations
Belgium	1914-1919
Finland	1888-1891
Germany	1914-1922
Italy	1901-6 (steam and motor missing), 1918-23 (sail missing), 1926-34 (all missing)
Sweden	1866-1869

Table A3. Imputations for basic oxygen tonnage

Country	Imputations for the international diffusion measure
Japan, United States	1952, 1953: basic oxygen and open hearth furnace output was estimated from total output in 1952 and 1953 and breakdown by process in 1954.

Canada	1955-1963: using breakdown by process in 1954, and electric arc output 1961-2, random values were ordered to reflect the time trend for BOF and open hearth output. These were used for the international diffusion measure only.
Australia	1962-1967: Using breakdown by process in 1968 and BOF capacity installed in 1962 (O'Malley 2000:723; Richards 2004), random values were ordered to reflect the time trends. Used for the international diffusion measure only.

Notes to Table A3. References used for 1962 figure for Australia: O'Malley, G.B. (2000) The Mineral Industries. Technology in Australia 1788-1988. Melbourne: Australian Academy of Technological Sciences and Engineering. Richards, P.N. (2004) "Ian Munro McLennan 1909-1998." Historical Records of Australian Science **15**(2).

Table A4. Countries included in the study

Technology	**Countries included**
Postal services	From 1830: Australia, Austria, Belgium, Denmark, Finland, France, Greece, Netherlands, New Zealand, Norway, Sweden. From a later year (*D*=10*/*D*=50*): Canada (1870/1830), Germany (1850), Ireland (1930), Italy (1860), Japan (1900), Portugal (1880/1830), Spain (1850/1830), Switzerland (1850/1830), United Kingdom (1840), United States (1890).
Shipping	Australia, Austria, Belgium, Canada*, Denmark, Finland, France, Germany, Italy*, Netherlands, New Zealand, Norway, Sweden, United Kingdom, United States. *Canada and Italy are not included in the international diffusion measure.
Steel	Australia (16 data points), Austria (18), Belgium (23), Canada (4), France (23), Germany (23), Italy (22), Japan (12), Netherlands (17), Spain (5), Sweden (22), United Kingdom (20), United States (24). The number of data points reflects the availability of data for the explanatory variables. In total, 443 observations of the domestic basic oxygen share and 510 observations of the international share were available, including data from Finland and Luxembourg.