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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.

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 Stoneman and Battisti (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 free-standing 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).[2]

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.

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

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[2] 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 Appendix A.

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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.[3] 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 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

$$D_t = z_t \left(\frac{D_t}{z_t}\right) \tag{1}$$

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

$$\Delta \ln D_t = \Delta \ln z_t + \Delta \ln w_t. \tag{2}$$

Eq. (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.[4] 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. Fig. A1 in Appendix A illustrates this worldwide diffusion of mail services[5] 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 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% 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 Fig. 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% 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

[3] 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).

[4] 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 Appendix A.

[5] Excluding both world war periods.