International Diffusion of Technological Change Within the Wood Products Industry: The Case of Particleboard

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During the past twenty-five years the world production of woodbased panels has grown rapidly at an average rate of ten percent per year [FAO 1975]. Moreover, within the group of structural wood-based panels, defined as the sum of plywood, particleboard and compressed fibreboard,[1] particleboard production has grown twice as fast during the same period. The world share of particleboard has in effect grown from a negligible level in 1950 to about 38 percent in 1973. This pattern of substitution has not been the same, however, in all countries. The displacement of plywood and fibreboard production by particleboard has been most rapid in Europe, the USSR and Oceania, moderate in North America and very small in Japan, where plywood production has taken the largest share of structural wood-based panels output. By looking at the data for individual countries one can observe even more striking differences with respect to the starting date of the diffusion of particleboard production, the velocity at which diffusion took place, and the ultimate limit of its share. The objectives of this paper are to report on the modeling of the particleboard production diffusion process for separate countries and to examine the differences in these models across countries.

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This research paper was developed from research supported by the School of Natural Resources, College of Agricultural and Life Sciences, and by the Graduate School, University of Wisconsin, Madison.

[1] Precise definitions of these products can be found in FAO [1976, p. xv].

[2] Such plots are given in an earlier manuscript [Buongiorno and Oliveira].

Model of Diffusion Within Countries

As pointed out above, the measure of the diffusion of particleboard used in this study is the share of particleboard within structural wood-based panels; i.e., $S_{it} = R_{it}/(R_{it} + F_{it} + L_{it})$, where S_{it} is the share of particleboard production in country i in year t, R_{it} is the production of particleboard, F_{it} is the production of compressed fibreboard, and L_{it} is the production of plywood. By plotting the value of S_{it} for a few countries, one can observe that all of the time series follow the sigmoid shape typical of many growth curves, with a slow start followed by an acceleration of the rate of substitution and finally a decrease of this rate.[2] Other studies have observed this pattern in the diffusion of new processes within industries and have usually modeled it with some form of a continuous function [Griliches, Mansfield, Swan]. In the present study the logistic model was selected for its relatively simple interpretation.

Employing the definition of S_{it}, the logistic diffusion process can be formulated as follows:

$$S_{it} = K_i/(1 + \exp(-a_i - b_i t)), \quad i = 1, 2, \ldots, N, \qquad (1)$$

where K_i, a_i, and b_i are constant parameters specific to country i, N is the number of countries, and t is time in years. To simplify notation the subscript i is omitted in the remainder of the paper.

Employing annual time series data from the period 1955-73 the parameters K, a, and b in (1) were estimated simultaneously via nonlinear least squares for twenty-five countries. The results are shown in table 1. As can be seen from the standard errors of the estimates, the logistic curves, in general, fit well the growth of particleboard production within each country. In general the 95 percent confidence intervals define the values of K, a, and b reasonably well even though these confidence intervals are only approximate since

Table 1. Characteristics of the diffusion of particleboard

Country	Logistic Model Parameters			Standard Error of Estimates	Starting Date t_o + 1950	Velocity of Diffusion DT (years)
	K	a	b			
Austria	.909	-2.806	.261	.002	1952	16.9
	(.02)	(.15)	(.02)		(.4)	(1.3)
Bulgaria	.642	-5.918	.631	.005	1956	7.0
	(.02)	(1.65)	(.16)		(1.2)	(1.8)
Czechoslovakia	.580	-5.368	.423	.002	1957	10.4
	(.01)	(.35)	(.03)		(.3)	(.7)
Denmark	.967	-1.089	.181	.003	1944	24.3
	(.05)	(.33)	(.05)		(3.5)	(6.7)
Finland	1.00	-3.601	.147	.003	1955	30.0
	(.75)	(.5)	(.04)		(5.5)	(8.1)
France	.643	-2.672	.266	.003	1952	16.5
	(.02)	(.2)	(.02)		(.6)	(1.2)
Germany (D.R.)	.885	- .574	.145	.003	1939	30.3
	(.05)	(.16)	(.01)		(1.8)	(2.1)
Germany (F.R.)	.938	-1.773	.183	.003	1948	24.0
	(.04)	(.11)	(.02)		(.8)	(2.6)
Greece	.579	-7.106	.442	.004	1961	10.0
	(.05)	(1.7)	(.12)		(1.0)	(2.7)
Hungary	.744	-3.654	.272	.005	1955	16.2
	(.06)	(.5)	(.05)		(1.0)	(3.0)
Ireland	.787	-5.738	.468	.007	1958	9.4
	(.04)	(1.3)	(.11)		(1.0)	(2.2)
Italy	.715	-4.223	.333	.005	1956	13.2
	(.04)	(.5)	(.05)		(.7)	(2.0)
Netherlands	.490	-5.517	.954	.004	1953	4.6
	(.01)	(1.3)	(.21)		(.6)	(1.0)
Norway	.639	-4.631	.424	.004	1956	10.4
	(.02)	(.6)	(.06)		(.6)	(1.5)
Poland	.461	-6.688	.603	.002	1957	7.3
	(.01)	(2.05)	(.16)		(1.4)	(1.9)
Spain	.647	-6.989	.492	.004	1960	8.9
	(.03)	(.85)	(.06)		(.6)	(1.1)
Sweden	.915	-4.187	.190	.002	1960	23.2
	(.28)	(.2)	(.03)		(1.7)	(3.7)
Switzerland	.928	- .571	.152	.002	1939	28.9
	(.03)	(.11)	(.02)		(2.0)	(3.8)
United Kingdom	.938	-1.960	.213	.005	1949	26.7
	(.05)	(.24)	(.03)		(1.3)	(2.9)
Yugoslavia	.491	-11.497	.938	.003	1960	4.7
	(.01)	(1.7)	(.14)		(.4)	(.7)
Australia	.557	-7.568	.495	.002	1962	10.3
	(.01)	(.6)	(.04)		(.4)	(.7)
New Zealand	.553	-7.568	.495	.002	1962	10.3
	(.03)	(.6)	(.04)		(.3)	(1.0)
U.S.S.R.	.497	-5.130	.360	.001	1958	12.2
	(.01)	(.3)	(.03)		(.2)	(1.0)
Canada	1.0	-4.597	.134	.001	1968	32.8
	(1.4)	(1.2)	(.02)		(11.5)	(4.9)
U.S.A.	1.0	-4.08	.127	.001	1965	34.6
	(.9)	(.7)	(.03)		(8.8)	(4.0)

Note: Numbers in parenthesis are standard errors.

they are calculated on the assumption that the model is linear with respect to the parameters around the calculated values. Parameters a and b are less accurately defined relative to K most likely due to the high correlation between the former two parameters.

Limit of the Diffusion Process

The estimation of the logistic diffusion curves reveals an interesting result. For most of the countries the limit of the diffusion process K is less than one, which shows that the substitution of particleboard has gone far enough in most countries to reveal a definitive saturation level. The exceptions are Finland, Canada and the United States. For the latter three countries the parameter estimates for a and b in table 1 were obtained under the constraint of K being equal to one. Similar to the above three countries, the saturation level for Sweden cannot be well defined from the national data alone. Thus, although its nonlinear least squares estimate of K (.915) is less than one, the 95 percent confidence interval for this estimate is very large.

A striking fact is that by 1973 most of the countries (except for the four listed above) seem very close to having reached their saturation level in terms of the possible diffusion of particleboard within the group of wood-based panels. Given the accuracy of the point estimates of the long-term shares, depicted by the 95 percent confidence interval, it is not possible to reject the null hypothesis that the equilibrium share of particleboard was already reached in 1973 for 20 of the 22 countries analyzed. Furthermore, there is a wide and statistically significant variation in the expected long-term share of particleboard from country to country.

Regarding Canada, Finland, Sweden and the United States an attempt has been made to estimate the long-term share of particleboard by pooling the information from these countries and from the other countries in the sample. Using only data from this latter set of countries the following logit relationship was observed:

$$\log\left[\frac{K}{1-K}\right] = \underset{(.10)}{.61}\, D10 - \underset{(.26)}{.68}\, W - .38, \qquad (2)$$

$$R^2 = .73, \text{ Standard Error} = .57,$$

where K is the expected long-term share calculated from the logistic diffusion curves, D10 is the time span (in years) it took for the share of particleboard production to grow from 10% to 20% of total wood-based panels production, and W is a dummy variable equal to 1 for eastern European countries, including Yugoslavia and the USSR, and to o for market economies. From (2) it appears that the early pattern of growth of the share of particleboard is a significant indicator of the ultimate share of particleboard within wood-based panels production. Countries with the slower initial growth are the ones which seem to achieve the higher long-term shares. Furthermore, eastern European countries generally achieve an ultimate share which is below the share achieved by market economies, everything else constant. The first explanation which comes to mind is that there may be in those countries a systematic policy to limit the development of particleboard. However in 1973 the German Democratic Republic had a particleboard share equal to 85% and it is still expected to grow towards 90%, although the 95% confidence interval on that estimate is quite large.[3]

Geographical Diffusion of the Particleboard Technology

The first industrial production of particleboard using synthetic resins is believed to have been operated in Bremen, in what is now the Democratic Republic of Germany, in 1941 [Moslemi, Akers]. The formidable expansion of particleboard industry in Europe began in the late 1940's, and most patents were emitted from Germany and Switzerland. Considerable effort would be needed to accurately pin point the year when the first particleboard plant started to operate commercially in each country. It is possible, however, to use the logistic curves calculated above to provide an estimate of the time when the diffusion of particleboard initiated, after defining somewhat arbitrarily an origin of the logistic process. Following Griliches and Swan the starting date of the diffusion of

[3] By employing relationship (2) long-term shares for Canada, Finland, Sweden, and the U.S. were estimated. These new estimates of K were in turn used to re-estimate the parameters a and b for these four countries. The results are presented in Buongiorno and Oliveira.

particleboard was defined as the time t_o when the share of particleboard reached 10% of the long-term equilibrium share K. Thus by substituting into (1), it is found that $t_o = (-2.2-a)/b$.

The results of the calculations in all countries show the Democratic Republic of Germany (1929), Switzerland (1939), Denmark (1944), and Federal Republic of Germany (1948) as the pioneering countries while Australia (1961), New Zealand (1962), USA (1965), and Canada (1968) are the late adopters. As an indication of the accuracy of these estimates the sample standard deviations of t_o are reported in table 1 and reveal that t_o is well defined for most countries, the notable exceptions being the late adopters.

A multiple regression analysis, the details of which are reported in Buongiorno and Oliveira, supported the hypothesis that other things being equal countries rich in wood supply have tended to postpone the introduction of particleboard production. This analysis also indicated that distance from the source of particleboard production (assumed to be the Democratic Republic of Germany) seemed to have a positive influence on the delayment of adoption (i.e., t_o). Furthermore, it was found that the importance of distance (with respect to t_o) decreased for countries further away from the innovation source.

Velocity of Diffusion Within Countries

Mansfield has shown that by defining P_t as S_t/K, the time DT necessary for P_t to grow from P_1 to P_2 is defined as:

$$DT = (1/b) \text{ Log } [(1-P_1) P_2/(1-P_2)P_1],$$

and is dependent only on P_1, P_2 and b. Setting $P_1 = .10$ and $P_2 = .90$ we then have $DT = 4.4/b$. This quantity which we adopt as our measure of the diffusion of the particleboard technology in each country depends only on the coefficient b and is extremely easy to interpret. In other words, it is the time necessary for the share of particleboard to grow from 10 percent to 90 percent of its long-term equilibrium share. The estimated values of DT and their standard deviations are reported in table 1. They show that the velocity of the diffusion of particleboard is accurately defined in most countries.

It was found through cross-sectional multiple regression analysis [Buongiorno and Oliveira] that DT was positively related to availability of raw material or wood supply and negatively related to gross domestic product growth during 1960-1970. These results indicate that although countries with a large supply of wood tended to be late adopters they were also relatively fast adopters. The regression analysis also indicated that the starting date of adoption, t_o, was not significantly related to DT.

Conclusion

In addition to demonstrating the successful application of logistic curves to the study of international particleboard production diffusion, the above analysis leads to the following conclusions: (i) there is wide variation in the expected long-term share of particleboard production across countries; (ii) except for Canada, Finland, Sweden and the U.S., most of the developed countries seemed close to having reached their long-term saturation level or production share by 1973; (iii) countries with slower initial growth in particleboard production seem to be the ones to achieve the higher long-term shares with respect to total wood-based panel production; (iv) *ceteris paribus* eastern European countries seem generally to achieve an ultimate production share which is 10% below the share achieved by market economies; (v) distance from the source of particleboard production (taken as the Decomratic Republic of Germany) and the availability of roundwood are positively related to (i.e., delay) the time of adoption of particleboard production; and (vi) *ceteris paribus* the velocity of the diffusion of particleboard production within countries seems to have been higher in countries with a high level of economic growth and lower in countries with high wood availability.

Useful extensions of the analysis would be the application of the empirical findings to forecasting particleboard diffusion in developing countries and, perhaps, determining which countries would be most successful with particleboard production.

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