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# Diffusion of Innovations in the World Textile Industry[*]

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This paper provides empirical evidence on how the international diffusion of industrial process innovations is affected by countries' levels of economic development. It analyses annual data on newly installed machinery in the spinning and weaving industries, where open-end rotors and shuttleless looms, respectively, represent easily identifiable innovations. A variable coefficient model, based on an S-shaped diffusion curve, is estimated from pooled data to assess the impact of the level of economic development on the diffusion of each innovation. It is found that the level of economic development affected the timing of the start of the diffusion process, but not the speed of diffusion within each country.

## I. Introduction

This paper is motivated by the crucial importance of the diffusion of technical progress across space. In traditional trade theory, the assumption is usually made that technology is costlessly available world-wide. More recent "North-South" models of trade and growth rely on other, more restrictive assumptions about the spread of technological knowledge. Obviously, the applicability of the theoretical results depends on which of the underlying assumptions approximate reality more adequately.

At a more pragmatic level, analysts of development policies have been concerned by the perceived inability of developing countries to adopt recent microelectronics-related process innovations (e.g., Kaplinsky

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(1984), pp. 157; Castells (1985), pp. 304; Henke (1990), pp. 8). It was suspected, therefore, that manufacturers in developing countries might lose international competitiveness, and that prospects for economic growth in developing countries would worsen.

Empirical studies on the creation and diffusion of technical progress have frequently analysed data on the diffusion of (product or process) innovations. Such data typically cover the diffusion of one innovation in a particular country or, at best, in a small number of countries at a similar level of economic development (e.g., Ray (1984)). Little information seems to be available on the diffusion of innovations across countries at different levels of development. Lücke (1993) has analysed data from the textile and steel industries relating to the shares of four innovative types of machinery in total capacity installed. Logistic diffusion curves were estimated for each country, and tests were performed for the influence of the level of economic development on the parameter estimates. The general finding was that the innovations under study diffused rapidly across countries. While adoption in developing countries was retarded in some cases, this could be related to the likely relative profitability of those innovations given different relative factor prices. At any rate, the level of economic development explained only a modest proportion of inter-country differences in the parameters of the diffusion curves.

This paper tests the robustness of these result by analysing annual data on the share of innovative machinery in *newly installed* equipment, or gross investment. Such data are available for the two textile industry innovations included in the previous study, i.e. open-end rotors vs. spindles in spinning and shuttleless vs. conventional looms in weaving. The data cover various developing and industrialized countries from 1974 through 1992. The robustness of my earlier findings is open to question because the share of innovative machinery in total capacity may be affected by changes in the competitiveness of firms that are unrelated to their technological behavior. For example, textile industries in high-wage countries have shrunk because of increased competition from firms of low-wage countries. Because obsolete machinery tends to be scraped first, a shrinking industry may experience an increase in the share of innovative machinery in total capacity without any corresponding change in the technological behaviour of firms. By contrast, the share of innovative machinery in *newly installed* equipment is unaffected by the shrinkage or expansion of productive capacity.[1]

Unfortunately, the use of data on newly installed machinery also entails problems that do not arise with data on total capacity. When annual purchases of equipment are small, the share of innovative equipment depends on a few individual orders, and may therefore fluctuate quite widely. The data are also affected somewhat by changes in the product composition of the output of national textile industries. Traditional equipment (ring spindles and conventional looms) still represents the preferred technology in some special applications that have become more important in the textile industries of some industrialized countries. Hence, the use of data on newly installed machinery complements, rather than supersedes, my earlier analysis.

The following section discuss the econometric model that is employed. The third section describes the data sources and criteria for the compilation of the dataset. It also characterizes briefly the technical attributes of the two innovations. The fourth section presents the empirical estimates, and the final section discusses the implications of the findings.

## II. Econometric Model

The emphasis in this paper is on possible cross-country differences in the diffusion of the two innovations, rather than on the determinants of adoption behaviour as such. The analysis therefore follows a two-stage approach. The first stage consists of describing the diffusion process and determining whether the relevant parameters differ across countries. An S-shaped logistic diffusion curve is estimated for each innovation with a full set of intercept and slope country dummies. In the second stage of the analysis, the estimated coefficients of the dummy variables are regressed on a measure of per capita GDP in order to determine whether inter-country differences in parameters are

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[1] Of course, gross investment itself is influenced by changes in the competitiveness of an industry.

related to the level of economic development.

This approach is in the tradition of early studies such as Griliches (1957) and Mansfield (1968) who used logistic diffusion curves to analyse the diffusion of particular innovations in different settings (e.g., hybrid corn in different US states, or diesel locomotives in different railroad companies). Since then, numerous case studies have confirmed that the simple logistic function is a powerful tool for describing and forecasting the diffusion of a wide variety of technical and social innovations (Marchetti (1990a, 1990b)). This is not surprising because a wide variety of diffusion models predict that the time path of the adoption rate will be S-shaped. Nevertheless, the more recent literature has introduced modifications to the approach taken in these early studies whose implications for the present analysis need to be considered.

First, the "epidemic" diffusion model underlying the simple logistic curve accounts only for the impact of information spreading on the adoption of an innovation (sometimes termed "internal" factors; cf. Lavaraj and Gore (1990)). Clearly, there are also economic, or "external" factors that act upon diffusion, such as changes in the relative profitability of conventional vs. new technology. Such external factors may be integrated into a diffusion model directly, rather than only indirectly by comparing diffusion processes in different environments (Karshenas and Stoneman (1992)). In the present paper, the consideration of "economic" factors would be possible only if the corresponding data were available for a fairly large number of countries. Relative profitability, for example, may well depend on the prevailing relative factor prices (cf. Section 3), in which case it would differ substantially between industrialized and developing countries. It has been found impossible to obtain, or construct, such time series of relevant economic data.

Second, a wide variety of more flexible functional forms have been used instead of the simple logistic function. This has been of particular concern in studies in the field of marketing where forecasting performance is of great practical importance. The dependent variable in such marketing-type models is usually the number of first adopters of an innovation in a certain period, while the spreading of information on the new technology is related to the cumulative total number of actual relative to potential adopters (Parker (1993), Karshenas and Stoneman (1992), Zettelmeyer and Stoneman (1993)). Thus it is explicitly acknowl- edged that new technology can only enter the capital stock through investment. This approach is clearly more realistic than the assumption underlying the simple epidemic diffusion model that the whole population may be affected by the "virus" of innovation at any time. An application of this approach is not possible in the present analysis, however, because there are no reliable data on the stock of machinery (cf. Section 3). Furthermore, while more flexible functional forms may be handled by non-linear estimation, this has been found to present problems with the data under study due to the relatively large number of parameters (time-series and cross-section-wise) that need to be estimated. Parsimony with respect to the number of explanatory variables and parameters is therefore an important consideration for the choice of the functional form in the present study.

Third, a number of studies, sometimes from a sociological perspective, have taken a closer looks at the attributes of firms that facilitate, or inhibit, innovation (cf. Gottinger (1991)). In such studies the dependent variable is most often the time elapsed before an innovation is first introduced in any particular unit of observation. This approach is only applicable if data are available on the behaviour of individual decision-making units (i.e., firms). In the present study, however, the focus is on the process of diffusion within countries.

The analysis in this paper differs from most other studies in that the dependent variable is the share of the new technology in gross investment, rather than in total capacity. The use of a logistic function to describe the time path of the adoption rate in gross investment may be justified in two ways. First, it may be argued that gross investment in a given year is a better measure of the adoption potential for the innovation than total capacity. The availability of information about the innovation is more closely related to the share of new technology in investment than to the corresponding share in total capacity. This would be true, for example, if both technologies are used side by side in individual firms and investment is not excessively lumpy, i.e. firms replace part of their capital stock at frequent intervals. In this case, a high share of new technology in current investment implies that a large proportion of firms have the opportunity to learn about the new technology. Under these conditions, the logistic diffusion curve may represent an acceptable approximation of the time path of the adoption rate in investment.

Second, if the adoption rate in total capacity follows an S-shaped time path, so will the adoption rate in gross investment. This result applies under a wide variety of plausible assumptions about depreciation rates and desired changes in total capacity. The adoption rate in investment, however, will normally be higher than in total capacity; further, the difference between the two shares increases along the time axis as long as the slope of the diffusion curve relating to total capacity increases (Antonelli, Petit and Tahar (1992), pp. 82f.). Hence, if the latter follows a logistic diffusion curve where the point of inflection is at 50 per cent of the saturation level, the adoption rate in investment will not exactly follow a logistic time path because its point of inflection will be above 50 per cent.

Thus there may be a specification problem if the symmetry assumption underlying the logistic diffusion curve turns out to be way off the mark. As an alternative, one might think of using other functional forms with few parameters that can be estimated by linear models, e.g., the log-normal cumulative distribution curve. Unfortunately, this approach does not offer a solution to the underlying problem. Linear estimation of such functional forms usually requires the log of the time index to be used as an independent variable. Hence the extent of non-linearity as well as the estimated parameters depend on the way the time index is defined (i.e., what year is to be $t=0$). This is undesirable in the present study where the time index has to be the same for a variety of countries where diffusion may have started at different times.

Therefore the logistic diffusion curve, despite its simplicity and possible shortcomings, is used to describe the evolution of the share of the two innovations in newly installed machinery. In the general form of the logistic function.

$$P_t = a/(1+\exp(b-ct)). \tag{1}$$

$P_t$ is the share of new machinery at time $t$, $a$ is the level of saturation, $b$ reflects the timing of the start of diffusion, and $c$ represents the speed of diffusion. Equation (2) below permits a more precise interpretation of parameters $b$ and $c$. The general form of the logistic function is nonlinear in variables and parameters. If the level of saturation is known a priori, $P_t$ may be redefined relative to the maximum adoption of the innovation ($P_t'$). As suggested by Fisher and Pry (1970), Equation (1) can then be transformed into

$$\ln(P_t'/(1-P_t')) = \mathrm{LOGIT}(P_t') = -b + ct, \tag{2}$$

where $P_t' = a/P_t$ .

It is now easily seen that the slope coefficient $c$ is directly related to the speed of diffusion: a higher value of $c$ implies, for each value of $P_t$, a larger increase in $P_t$ over time. The intercept coefficient ($-b$) indicates the implied value of LOGIT($P_t'$) in year t=0 which may be thought of as the year when the diffusion of the innovation started. For a given speed of diffusion $c$, ($-b$) is larger the earlier in time the diffusion of the innovation takes place.

In order to allow coefficients to differ across countries, a full set of intercept and slope dummies is included in (2):

$$\mathrm{LOGIT}\,(P_{t,k}') = -b_0^* - b_1^* D_1 - \cdots - b_{k-1}^* D_{k-1} + c_0^* t + c_1^* D_1 t + \cdots + c_{k-1}^* D_{k-1} t \tag{3}$$

where $k=1, \cdots, K$ is the country index, superscript $*$ indicates that $b_1^*, \cdots, b_{k-1}^*$ and $c_1^*, \cdots, c_{k-1}^*$ are the country-specific deviations from coefficients $b_0^*$ and $c_0^*$, and residuals are neglected for the time being. Equation (3) represents the first stage of our econometric model. It describes adoption behaviour in each country, but does not itself permit hypothesis testing.

The second stage of the econometric model involves testing the hypotheses that the start of diffusion ($-b$) or the speed of diffusion hypotheses that the start of diffusion (-$b$) or the speed of diffusion within each country (parameter $c$) are positively related with a country's level of economic development. This is done by estimating

$$-b_k^* = \alpha_1 + \beta_1 RGDP_k \tag{4}$$

and

$$c_k^* = \alpha_2 + \beta_2 RGDP_k \tag{5}$$

with $k=1, \cdots, K$; $RGDP$: real gross domestic product per capita. In these regressions, $b_K^*$ and $c_K^*$ are set to 0 because the coefficients applicable to country $K$ in equation (3) are by definition the sample coefficients $b_0^*$ and $c_0^*$.

Thus, a positive estimate of $\beta_1$ implies that the diffusion of the innovation started earlier (on average) the higher a country's per capita GDP. Similarly, a positive estimate of $\beta_2$ implies that the diffusion of the innovation proceeded faster (on average) the higher a country's per capita GDP. Equation (3), (4), and (5) together form our econometric model.

Since the functional form of equations (4) and (5) is not clear a priori, they are also estimated in semi-loglinear form with ln$RGDP$ as the independent variable. The semi-loglinear form allows for the possibility that the increases in ($-b_k^*$) and $c_k^*$ in response to rising per capita income are large at low income levels, but become smaller as per capita income rises. Estimation of (4) and (5) needs to account for possible heteroskedasticity of the residuals because $b_k^*$ and $c_k^*$ are themselves random variables.

Equations (4) and (5) may be substituted into (3) to form a one-pass regression model to estimate $\beta_1$ and $\beta_2$:

$$\text{LOGIT}\ (P_{t,k}') = \alpha_1' + \beta_1 GRDP_k + \alpha_2' t + \beta_2 RGDP_k\ t \tag{6}$$

where $\alpha_1' = \alpha_1 + b_0^*$; $\alpha_2' = \alpha_2 + c_0^*$.

Under certain restrictive assumptions about the residuals in (3), (4), and (5), consistent weighted least squares estimators of $\beta_1$ and $\beta_2$ can be derived such that estimating equation (6) is equivalent to estimating (3), (4), and (5) separately (Amemiya (1978), pp. 795). These restrictive assumptions, however, particularly the absence of serial autocorrelation in (3), are unlikely to apply in the present context because of the inevitable shortcomings of our rather simple model. Therefore the one-pass and two-step procedures will be applied alternatively, and the estimates will be tested for the likely problems of autocorrelation and heteroskedasticity.

## Ⅲ. Data

Open-end rotors in spinning and shuttleless looms in weaving have in common that they have been adopted on a large scale in countries at widely different levels of economic development. It is plausible to assume, therefore, that they reduce per-unit production costs under a wide range of relative factor prices.[2] Nevertheless, adoption of these innovations leads to increased labour productivity, affecting unskilled as well as skilled labour, while fixed capital requirements per unit of output tend to rise (Lücke (1990) pp. 142).[3] Therefore the relative profitability of innovative and conventional equipment may be affected by the relative prices of factors of production. In the case of both open-end rotors and shuttleless looms, the adoption rates for each year of observation are positively correlated with per-capita GDP as a proxy for the level of economic development.

While open-end rotors represent a major technological improvement over conventional ring spindles, their application is still limited to low-quality yarns. The data assembled in Table 1 show that in many countries the share of rotors in newly installed spinning machinery has

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[2] The technical characteristics of both types of machinery are described concisely in Toyne (1984), pp. 37ff.)) and Antonelli, Petit and Tahar (1992), pp. 90ff.). Ripken (1981) provides a detailed account of the technological development and adoption of open-end rotors.

[3] I avoid using the terms of "factor-saving" vs. "neutral" technical progress, which are normally employed to characterize a shift in a neoclassical, substitutional production function. By contrast, the present discussion relates to the choice between several distinct techniques.

even decreased since the mid-1980s. This is especially true for Western Europe where the textile industry has concentrated on high-quality market segments. The limited applicability of open-end rotors raises several problems for the empirical estimation of the logistic diffusion curve. The saturation level may not only be considerably below 100 per cent, but may also differ across countries.

Such problems do not exist in the case of the various types of shuttle-less looms which have now replaced conventional looms entirely in newly installed machinery in many developed countries. This is not immediately clear from the data presented Table 2 because once the share of new machinery reached 100 per cent, only one such observation was included in the dataset for the regressions (changed to 99.9 per cent to permit the LOGIT transformation). The number of such datapoints would be essentially arbitrary once an innovation has diffused completely, and inclusion of a larger number would push the estimate of *b* and *c* in equation (1) downward. An alternative procedure would consist in estimating equation (3) by non-linear least squares. However, this turned out to be technically impossible because of the large number of parameters (dummy variables) whose estimates did not converge in the estimation procedure.

The data analysed in this paper are based on information supplied to International Textile Manufacturers Federation by producers of textile machinery. The data source states that in the early 1990s these data covered the vast majority of would-wide shipments of textile machinery except for China. Over the years, however, the coverage of the data source has varied somewhat. Although such variations are more likely to affect absolute numbers than the share of innovative machinery, they inevitably introduce an element of uncertainty. The analysis uses data for all countries for which the data source gives at least five observations.[4]

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[4] It may be noted that these data on annual shipments are frequently not consistent with the stock data used in Lücke (1993), although the latter are also published by the International Textile Manufacturers Federation. The data on installed capacity are based on estimates of national textile industry associations, which are known not to be very accurate sometimes. There is therefore no sound way of calculating the annual number of first adopters of the innovations, e.g., as the difference in stocks at the beginning of two consecutive years. This would otherwise be highly desirable because the number of

## IV. Empirical Results

Regression results are presented in Table 3 for open-end rotors and in Table 4 for shuttleless looms. The coefficients $\beta_1$ and $\beta_2$ have been estimated both by the "one-pass" model according to equation (6), and by the explicit two-stage procedure described by equations (3), (4), and (5). In the case of open-end rotors, where the saturation level is not clear a priori, equations (6) and (3) have been estimated for alternative saturation levels searching for the best fit of the transformed linear model.[5] "Local maxima" of the adjusted coefficient of determination have been found at saturation levels of 70 and 100 per cent, and results are reported for both values.

The one-pass estimates (equation (6)) are affected by substantial first-order correlation as well as heteroskedasticity.[6] Visual inspection of the residuals reveals that frequently nearly all residuals for individual countries have the same sign. Hence, the variable coefficient model apparently captures only part of the true inter-country variation of the parameters of the diffusion curves. This hypothesis is confirmed by the regression results for equation (3) where the variable coefficient approach is replaced by a full set of intercept and slope dummies. Both first-order autocorrelation and heteroskedasticity are much reduced.

Overall, the logistic curve fits the data for shuttleless looms better than for open-end rotors, judging by the adjusted coefficients of determination for equation (3) (.71 vs. .47 or .48). This finding is

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first adopters in a given period is used as the dependent variable in many diffusion models of the marketing variety employing more flexible functional forms.

[5] Non-linear least squares estimation of equation (1) has also been attempted for the diffusion of open-end rotors in order to allow the saturation level to vary across countries. Unfortunately, the results of the iterative procedure did not converge, apparently because the required number of dummy variables was too large. Alternatively, the level of saturation was assumed the same for all countries, but was allowed to change over time (i.e., parameter $a$ in equation (1) was made a linear function of time and time squared). Again estimation failed, presumably because the parameters in equation (1) were no longer very well identified. It was possible, however, to reproduce the results for equation (6) contained in Table 3 using nonlinear least squares instead of the transformed linear model.

[6] Since the analysis uses annual data, tests for higher-order autocorrelation have not been performed.

explained by the more limited applicability of rotors in general, as well as the associated differences across countries. In order to test for possible nonlinearities, a squared time trend was added to the explanatory variables in equation (3) along with a full set of slope dummies. An F-test was then performed to check whether the coefficients of these additional variables are jointly zero. The null hypothesis was rejected in all three cases at the 5 per cent level of significance at least. While this finding cautions against an uncritical reading of the regression results, the parameters of the "quadratic" model itself do not have a ready economic interpretation, nor does there appear to be a practical alternative model given the limitations of the available data.

The estimates of $\beta_1$ based on the explicit two-stage model (equation (4)) are positive and significantly different from zero for both open-end rotors (assuming a 70 per cent saturation level) and for shuttleless looms. The estimate for open-end rotors, assuming a 100 per cent saturation level, has a p-value of .111. In each case, the coefficient estimates are also of a comparable order of magnitude to the estimates based on equation (6). This seems noteworthy given the substantial autocorrelation and heteroskedasticity problems in the latter. Hence a fairly robust conclusion may be drawn that both innovations started to diffuse later in less developed countries. As the adjusted coefficients of determination for equation (4) never exceed .20, however, it may also be concluded that the influence of the level of economic development on the timing of the start of diffusion was limited.

With only one exception, the estimates of $\beta_2$ based on either equation (5) or (6) are not significantly different from zero. Furthermore, the "deviant" estimate for shuttleless looms based on equation (6) can be considered less reliable than the estimate based on equation (5) because equation (6) is affected by substantial first-order autocorrelation and heteroskedasticity. In sum, therefore, these results suggest that the level of economic development has not exerted a significant influence on the speed of the diffusion of the two process innovations as measured by $\beta_2$.

These findings are broadly in agreement with my earlier study that analysed data relating to the share of innovative machinery in total capacity (Lücke (1993)). My earlier study also found that the level of economic development played only a limited role in the adoption of new technologies.[7] Furthermore, for open-end rotors I found a statistically significant impact of per capita GDP only on the timing, but not on the speed of diffusion - like in the present study. However, my present findings diverge from the earlier study in the case of shuttleless looms. In Lücke (1993), the two-step estimate of $\beta_1$ - corresponding to equation (4) - was not statistically significant, whereas the two-step estimate of $\beta_2$ - corresponding to equation (5) - was significant. This is the reverse of my present findings. At the same time, in the one - pass estimates corresponding to equation (6), both coefficient estimates were statistically significant - like in the present study. My earlier results on shuttleless looms were difficult to interpret because there is no technological difference between the two innovations that could account for a marked difference in adoption behaviour. The present findings suggest that the perceived difference probably reflects the inevitable inaccuracy of the estimation procedure rather than any fundamental factors.

## V. Conclusions

The data analysed in this paper indicated that throughout the period of observation the adoption rates of the two innovations in individual countries were positively correlated with the level of economic development. The estimates of the logistic diffusion curves provide evidence that this reflects the fact that diffusion tended to start earlier in more developed countries. This finding may be explained with respect to the relative profitability of new versus conventional technology, which is likely to be higher in more developed countries because both innovations tend to raise labour, rather than capital, productivity. A related argument is that, at an early stage, application of the new machinery may have required a relatively large amount of human capital, a scarce factor in developing countries. No significant link is found, however, between the speed of diffusion within each

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[7] $\overline{R}^2$ for the equations corresponding to (4) and (5) was never above .21.

country and the level of economic development.

If one assumes a steady stream of productivity-raising process innovations, these findings support the hypothesis that there exists a "technology gap" or, by implication, productivity gap between countries at different levels of economic development.[8] It may be noted, however, that a gap in physical productivity need not translate into reduced competitiveness of the less productive countries if factor prices differ. The empirical findings also suggest that the productivity gap does not increase over time, since the speed of diffusion within individual countries does not appear to depend on the level of economic development, once the process has begun.

The relatively rapid diffusion of the two process innovations even in developing countries might reflect the fact that they are embodied in physical capital, have attained a high degree of technological maturity, and no longer require a large amount of human capital in application. Furthermore, new textile technology is now predominantly developed by equipment manufacture, rather than producers of textiles. Equipment manufacturers are not very likely to inhibit access to new technology by textile producers based in developing countries. It would be interesting therefore to study the international diffusion of more recent innovations in fields like microelectronics, biotechnology, and new materials where these conditions may not apply.

Another possible extension of the present work would involve the use of data for individual enterprises from a variety of countries. Such a study of adoption behaviour at the micro level could further illuminate those determinants like the relative profitability of different machinery that are reflected only imperfectly by per capita income. Such a study would also capture potentially important sectoral or firm-specific factors which cannot be accounted for fully by the presently available data.

At the outset of this paper the question has been raised of whether the assumption of instantaneous diffusion of new technology is an acceptable approximation of reality. Our analysis demonstrates that

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[8] Krugman (1985) presents a one-factor model of the possible implications for the international division of labour. With more than one factor of production, the weighting of single factor productivities to calculate total factor productivity for the purpose of an international comparison involves difficult conceptual problems.

this assumption does not hold literally. It also suggests, however, that if there exists a productivity gap, it does not appear to widen over time. If this finding can be generalized, the assumption of instantaneous diffusion may still be a useful abstraction under many circumstances.

**Table 1 Share of Open-end Rotors in Newly Installed Spinning Machinery, 1974-1992 (per cent)**[a]

| | Ø1974-77 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 |
|---|---|---|---|---|---|---|---|---|
| Egypt | 2.1 | 20.4 | 52.8 | 5.8 | 2.9 | 4.7 | 2.9 | n.a. |
| Morocco | 16.8 | 90.4 | 83.6 | n.a. | 21.4 | 76.1 | 5.6 | 11.0 |
| Nigeria | 2.6 | 25.0 | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| South Africa | n.a. | n.a. | 27.8 | 9.9 | 2.0 | 3.0 | n.a. | 26.9 |
| Canada | 88.9 | 38.6 | n.a. | 17.2 | 18.8 | n.a. | 50.3 | 77.2 |
| Mexico | 34.6 | 12.4 | 22.6 | 8.4 | 6.1 | 4.1 | n.a. | 49.5 |
| U.S.A. | 49.0 | 32.5 | 63.9 | 40.3 | 53.0 | 51.2 | 71.2 | 97.6 |
| Argentina | n.a. | n.a. | 25.7 | 16.0 | 30.8 | n.a. | 14.7 | 21.8 |
| Brazil | 8.0 | 3.0 | 7.1 | 10.4 | 8.9 | 8.7 | 5.1 | 4.3 |
| Columbia | 11.0 | 8.2 | 71.5 | 33.5 | 27.8 | 8.9 | n.a. | n.a. |
| Ecuador | n.a. | 35.5 | 72.7 | n.a. | 5.0 | n.a. | n.a. | 11.0 |
| Peru | n.a. | n.a. | 17.2 | 9.2 | 9.7 | 75.0 | 15.3 | n.a. |
| Venezuela | 13.1 | 21.9 | n.a. | n.a. | n.a. | n.a. | n.a. | 16.5 |
| Hong Kong | 86.1 | 91.7 | 20.4 | 22.6 | 94.8 | n.a. | 46.2 | 45.8 |
| Bangladesh | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| China | n.a. | n.a. | 39.0 | 48.4 | 50.4 | n.a. | n.a. | 22.6 |
| India | n.a. | 0.1 | 0.0 | 12.5 | 1.1 | 1.5 | 0.2 | 0.5 |
| Indonesia | 1.4 | 2.7 | n.a. | n.a. | 9.1 | 0.9 | n.a. | 54.4 |
| Japan | 40.3 | 15.3 | 21.0 | n.a. | 16.6 | 7.0 | 38.9 | 22.9 |
| Korea. Rep. | 2.5 | 2.2 | 6.7 | 29.9 | 10.8 | 1.8 | 2.2 | 44.5 |
| Pakistan | n.a. | n.a. | 17.1 | 19.4 | 5.0 | n.a. | 7.0 | n.a. |
| Philippines | n.a. | n.a. | 4.7 | n.a. | n.a. | 38.9 | n.a. | n.a. |
| Taiwan. R.O.C. | 24.8 | 45.4 | 22.9 | 45.3 | 14.7 | 74.4 | 15.3 | 5.6 |
| Thailand | n.a. | n.a. | n.a. | n.a. | 13.0 | 9.1 | 3.8 | 4.8 |
| Belgium | 72.4 | 59.9 | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| France | 55.3 | 72.4 | 75.0 | 42.5 | 68.4 | 64.0 | 64.3 | 61.7 |
| Germany. F.R. | 28.8 | 15.3 | 31.4 | 44.6 | 51.8 | 73.5 | 76.2 | 54.8 |
| Greece | 3.9 | 1.5 | n.a. | 12.2 | 26.4 | 7.1 | 23.0 | 83.3 |
| Italy | 22.2 | 13.1 | 8.5 | 13.0 | 27.6 | 22.8 | 49.4 | 42.4 |
| Portugal | n.a. | n.a. | 23.1 | 9.3 | 11.5 | 2.5 | 2.4 | 4.6 |
| Spain | 23.2 | 31.1 | 24.5 | 16.9 | 15.2 | 54.1 | 57.3 | 36.7 |
| U.K | 18.6 | 59.8 | 92.5 | n.a. | n.a. | 55.3 | 10.7 | n.a. |
| Austria | 3.4 | 33.7 | 5.7 | 1.7 | 7.7 | 87.0 | 15.3 | 39.7 |
| Switzerland | n.a. | n.a. | 13.2 | 13.3 | 3.8 | 6.4 | 2.3 | 30.4 |
| Poland | n.a. | 78.1 | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| Turkey | 1.8 | 26.1 | n.a. | 57.9 | 25.8 | 22.3 | 22.9 | 37.9 |
| No. of Observations | 23 | 26 | 26 | 24 | 29 | 25 | 24 | 26 |
| Mean | 26.6 | 32.2 | 32.7 | 22.5 | 22.1 | 30.4 | 25.1 | 34.9 |
| Correlation coefficient (share of open-end rotors/RGDP1) | 0.72 | 0.31 | 0.10 | 0.11 | 0.47 | 0.36 | 0.72 | 0.62 |

## Table 1 Continued

| | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | RGDP1 (1985)[b] |
|---|---|---|---|---|---|---|---|---|---|
| Egypt | n.a | n.a | n.a | n.a | n.a | n.a | n.a | 1.4 | 1188 |
| Morocco | 31.5 | 55.2 | 76.1 | 6.6 | 30.1 | 29.0 | 5.3 | 56.1 | 1221 |
| Nigeria | 32.8 | 40.8 | 20.6 | 39.3 | n.a | 52.2 | n.a | 20.3 | 581 |
| South Africa | 25.5 | 56.4 | 64.5 | 28.2 | 39.1 | 17.4 | 29.2 | 8.1 | 3885 |
| Canada | 95.2 | n.a | n.a | n.a | n.a | n.a | n.a | n.a | 12196 |
| Mexico | 21.7 | 43.5 | 80.1 | 46.8 | 43.4 | 18.6 | 44.1 | 44.5 | 3985 |
| U.S.A. | 96.5 | 97.8 | 86.5 | 64.7 | 51.7 | 66.4 | 65.9 | 89.3 | 12532 |
| Argentina | 38.5 | 23.8 | 36.6 | 27.5 | 32.0 | 59.9 | 60.4 | 17.4 | 3486 |
| Brazil | 3.3 | 17.9 | 9.1 | 12.7 | 8.8 | 11.0 | 12.0 | 12.7 | 3282 |
| Columbia | n.a | 75.1 | 22.7 | 78.4 | 15.7 | n.a | n.a | 29.4 | 2599 |
| Ecuador | 78.2 | 56.9 | 91.2 | n.a | 20.7 | 13.9 | 22.0 | 23.4 | 2387 |
| Peru | 20.7 | 19.0 | 7.9 | n.a | 73.8 | 29.5 | 30.5 | 7.9 | 2114 |
| Venezuela | 47.1 | n.a | 54.5 | 74.7 | 56.9 | n.a | n.a | 47.8 | 3548 |
| Hong Kong | n.a | n.a | 95.4 | 93.6 | 42.7 | n.a | n.a | 67.1 | 9093 |
| Bangladesh | n.a | 35.0 | 3.9 | 23.6 | 26.5 | 21.6 | 15.7 | n.a | 647 |
| China | 90.9 | 80.0 | 75.0 | 61.9 | 33.7 | 33.7 | 33.7 | 6.0 | 2444 |
| India | 2.0 | 3.4 | 2.4 | 8.2 | 14.2 | 8.0 | 3.2 | 2.2 | 750 |
| Indonesia | 25.7 | 26.4 | 14.9 | 24.7 | 11.7 | 5.4 | 3.2 | 10.7 | 1255 |
| Japan | 10.5 | 19.5 | 10.3 | 3.0 | 14.8 | 7.7 | 1.1 | 0.5 | 9447 |
| Korea. Rep. | 36.0 | 6.7 | 7.5 | 25.2 | 1.7 | 1.4 | 6.5 | 0.9 | 3056 |
| Pakistan | 19.7 | 48.9 | 17.1 | 8.5 | 1.7 | 3.1 | 1.2 | 2.0 | 1153 |
| Philippines | n.a | 17.2 | 24.8 | 56.9 | 37.2 | 39.4 | 17.8 | 36.2 | 1361 |
| Taiwan. R.O.C. | 5.3 | 17.9 | 24.8 | 24.5 | 10.2 | 0.4 | 22.3 | 6.6 | 3581 |
| Thailand | 16.2 | 50.6 | 27.1 | 13.9 | 6.0 | 9.8 | 6.3 | 3.1 | 1900 |
| Belgium | 90.3 | 95.3 | 55.8 | 67.4 | 70.5 | 69.4 | 53.4 | n.a | 9717 |
| France | 63.6 | 41.1 | 72.1 | 60.8 | 45.0 | 65.7 | n.a | 57.7 | 9918 |
| Germany. F.R. | 69.3 | 28.5 | 54.5 | 32.1 | 21.5 | 19.4 | 36.3 | 62.9 | 10708 |
| Greece | 12.0 | 25.5 | 25.2 | 19.0 | 1.1 | 46.3 | 4.0 | 25.3 | 4464 |
| Italy | 57.0 | 40.0 | 27.8 | 30.3 | 16.9 | 14.4 | 14.1 | 14.2 | 7425 |
| Portugal | 59.1 | 34.1 | 11.9 | 19.0 | 14.9 | 21.9 | 38.1 | 31.5 | 3729 |
| Spain | 79.8 | 84.8 | 62.1 | 48.8 | 24.7 | 24.8 | 29.1 | 66.1 | 6437 |
| U.K | n.a | n.a | n.a | 92.7 | n.a | n.a | n.a | n.a | 8664 |
| Austria | 17.3 | 22.3 | 29.8 | 34.5 | 24.3 | 7.1 | 16.9 | 9.5 | 9713 |
| Switzerland | 36.1 | 65.6 | 10.5 | 19.8 | 21.5 | 1.9 | n.a | 9.2 | 10640 |
| Poland | 94.8 | n.a | 97.7 | n.a | 65.6 | 77.2 | n.a | n.a | 4913 |
| Turkey | 32.2 | 15.8 | 21.6 | 24.5 | 11.8 | 31.7 | 17.2 | 45.2 | 2533 |
| No. of observations | 30 | 30 | 33 | 31 | 32 | 30 | 26 | 31 | |
| Mean | 43.6 | 41.5 | 40.1 | 37.8 | 27.8 | 26.9 | 22.7 | 26.3 | |
| Correlation coefficient (share of open-end rotors/RGDP1) | 0.47 | 0.34 | 0.33 | 0.35 | 0.27 | 0.22 | 0.46 | 0.45 | |

Notes: a. One rotor is counted as equivalent to three spindles (Antonelli, Petit, Tahar, 1992, pp. 101).

b. In US$ at 1980 international prices.

Source: International Manufacturers Federation, *International Textile Machinery Shipment Statistics*, various issues; Heston, Summers (1988); own calculations.

Table 2 Share of Shuttleless Looms in Newly Installed Weaving Machinery, 1974-1992 (per cent)

| | ∅1974-77 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 |
|---|---|---|---|---|---|---|---|---|
| Algeria | 6.6 | 76.7 | 39.4 | 67.5 | 90.6 | n.a | 92.3 | n.a |
| Egypt | 1.6 | 2.1 | 1.9 | 7.3 | 25.0 | 64.0 | 71.1 | 91.1 |
| Nigeria | 13.3 | 23.9 | 87.3 | 73.5 | 36.4 | 60.0 | n.a | n.a |
| Canada | n.a | n.a | 64.0 | 97.0 | 98.8 | n.a | n.a | 91.5 |
| Guatemala | n.a | n.a | 65.6 | n.a | 2.6 | n.a | n.a | 50.0 |
| Mexico | 49.8 | 73.2 | 59.8 | 84.1 | 85.9 | 91.3 | 77.0 | 76.8 |
| U.S.A. | 63.2 | 89.4 | 80.9 | 91.6 | 98.0 | 99.0 | - | 97.4 |
| Brazil | 23.9 | 82.1 | 15.6 | 21.0 | 34.8 | 52.2 | 46.9 | 49.0 |
| Colombia | 67.1 | 76.1 | 92.5 | 90.6 | 98.5 | 77.0 | n.a | n.a |
| Bangladesh | n.a | n.a | n.a | n.a | n.a | n.a | n.a | n.a |
| China | n.a | n.a | n.a | n.a | 36.9 | n.a | 68.1 | 98.5 |
| Hong Kong | 9.2 | 44.1 | 79.1 | 91.6 | 99.3 | 90.1 | n.a | n.a |
| India | 3.0 | 12.8 | 3.4 | 4.1 | 3.3 | 6.5 | 7.7 | 16.9 |
| Indonesia | 4.8 | 12.6 | 22.5 | 7.0 | 42.5 | 16.8 | 14.3 | 16.2 |
| Iran | 11.7 | 32.8 | 16.7 | n.a | 30.4 | 14.7 | 81.1 | n.a |
| Iraq | 2.1 | 78.0 | 83.9 | 71.3 | 89.2 | 92.6 | n.a | n.a |
| Israel | 71.8 | 26.9 | 54.6. | 10.0 | 41.2 | 95.7 | 84.3 | 85.7 |
| Japan | 15.1 | 49.8 | 48.0 | 57.4 | 57.0 | 52.0 | 74.0 | 76.4 |
| Korea Rep. | 5.3 | 22.3 | 21.7 | 79.3 | 16.9 | 9.4 | 12.6 | 26.8 |
| Pakistan | 17.4 | 5.4 | 6.5 | n.a | n.a | 17.5 | n.a | 2.8 |
| Philippines | n.a | n.a | 29.2 | 66.7 | 2.0 | 26.8 | 28.1 | 32.3 |
| Sri Lanka | n.a | n.a | n.a | n.a | n.a | 50.0 | n.a | 40.0 |
| Syria | n.a | n.a | 10.3 | n.a | 26.9 | 99.8 | n.a | n.a |
| Taiwan, R.O.C. | 12.7 | 80.0 | 81.2 | n.a | 53.9 | 62.5 | 75.6 | 95.9 |
| Thailand | n.a | n.a | 10.4 | 18.7 | 39.0 | 36.3 | 30.9 | 11.9 |
| Belgium | 68.8 | 86.5 | 97.9 | 94.1 | 99.4 | 99.7 | 99.5 | n.a |
| France | 66.2 | 96.5 | 91.9 | 90.6 | 96.8 | 98.5 | 99.3 | 98.3 |
| Germany, F.R. | 55.5 | 87.1 | 92.1 | 92.6 | 99.2 | 97.3 | 98.9 | 99.9 |
| Italy | 67.9 | 91.9 | 93.0 | 84.1 | 91.0 | 98.4 | 99.7 | 99.6 |
| Portugal | 42.0 | 70.2 | 78.7 | 74.7 | 77.1 | 96.3 | 97.6 | n.a |
| Spain | 50.9 | 37.4 | 65.5 | 81.3 | 96.6 | 99.2 | n.a | 99.9 |
| U.K. | 57.0 | 62.3 | 84.9 | 65.7 | 53.5 | 85.9 | 99.7 | 97.9 |
| Austria | 74.8 | 82.8 | 96.3 | 92.7 | 94.8 | 96.7 | 91.5 | n.a |
| Sweden | 70.5 | 78.3 | 98.3 | n.a | n.a | 82.9 | n.a | 94.4 |
| Switzerland | 62.3 | 90.2 | 92.4 | 83.9 | 80.2 | 87.3 | 92.3 | n.a |
| Poland | 93.1 | 99.6 | 52.7 | n.a | n.a | n.a | n.a | n.a |
| Turkey | 23.6 | 18.5 | 39.7 | n.a | 75.5 | 72.8 | 61.3 | 69.8 |
| No. of observations | 29 | 29 | 34 | 26 | 32 | 31 | 23 | 24 |
| Mean | 38.3 | 58.3 | 57.6 | 65.3 | 61.7 | 68.7 | 69.7 | 67.5 |
| Correlation coefficient (share of shuttleless looms/RGDP1) | 0.63 | 0.59 | 0.64 | 0.59 | 0.66 | 0.63 | 0.70 | 0.69 |

## Table 2 Continued

| | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | RGDP1 (1985)[a] |
|---|---|---|---|---|---|---|---|---|---|
| Algeria | 98.2 | 79.8 | 31.0 | n.a | n.a | n.a | n.a | n.a | 2142 |
| Egypt | n.a | 80.5 | 48.1 | 48.9 | n.a | n.a | 90.5 | n.a | 1188 |
| Nigeria | n.a | n.a | n.a | n.a | n.a | n.a | n.a | 79.6 | 581 |
| Canada | n.a | 75.7 | 93.5 | n.a | n.a | n.a | n.a | n.a | 12196 |
| Guatemala | 96.0 | n.a | 96.8 | n.a | n.a | n.a | n.a | n.a | 1608 |
| Mexico | 93.4 | 90.6 | 82.9 | 92.5 | 99.4 | 92.4 | 98.5 | n.a | 3985 |
| U.S.A. | n.a | 99.9 | n.a | n.a | n.a | n.a | 99.2 | n.a | 12532 |
| Brazil | 26.1 | 57.5 | 45.9 | 77.8 | 73.7 | 92.0 | 92.1 | 93.8 | 3282 |
| Colombia | 90.6 | 97.1 | 63.4 | n.a | n.a | n.a | n.a | n.a | 2599 |
| Bangladesh | 0.3 | 0.3 | n.a | n.a | n.a | 35.0 | 22.7 | 6.7 | 647 |
| China | n.a | 95.6 | n.a | 99.6 | 99.2 | 90.8 | 90.1 | 97.4 | 2444 |
| Hong Kong | n.a | 93.9 | 97.5 | n.a | n.a | n.a | n.a | n.a | 9093 |
| India | 12.6 | 17.6 | 12.8 | 6.3 | 13.9 | 17.6 | 9.6 | 32.6 | 750 |
| Indonesia | 74.5 | 64.1 | 86.2 | 81.9 | 76.1 | 63.7 | 51.3 | 66.9 | 1255 |
| Iran | 67.9 | 91.8 | 80.2 | n.a | 99.3 | 95.3 | n.a | n.a | 3922 |
| Iraq | 3.8 | 60.0 | n.a | 95.7 | n.a | n.a | n.a | n.a | 2813 |
| Israel | 97.8 | n.a | n.a | n.a | n.a | n.a | n.a | n.a | 6270 |
| Japan | 84.7 | 85.3 | 89.0 | 90.8 | 91.9 | 97.0 | 98.8 | 97.8 | 9447 |
| Korea Rep. | 22.6 | 24.7 | 34.8 | 46.2 | 56.9 | 67.4 | 86.0 | 86.2 | 3056 |
| Pakistan | 10.9 | 29.4 | 47.0 | 50.7 | 55.6 | 67.0 | 64.0 | 61.6 | 1153 |
| Philippines | n.a | n.a | 88.9 | n.a | n.a | 30.3 | 52.9 | n.a | 1361 |
| Sri Lanka | n.a | 17.6 | 31.0 | n.a | n.a | n.a | 25.0 | 3.2 | 1539 |
| Syria | n.a | 17.9 | n.a | 22.6 | 20.3 | 51.0 | 37.5 | n.a | 2900 |
| Taiwan, R.O.C. | 99.9 | 99.6 | n.a | n.a | 99.5 | n.a | n.a | n.a | 3581 |
| Thailand | 78.7 | 80.4 | 96.8 | n.a | 98.2 | 97.3 | 93.2 | 90.0 | 1900 |
| Belgium | 99.5 | n.a | n.a | n.a | n.a | n.a | n.a | n.a | 9717 |
| France | n.a | n.a | 97.9 | n.a | n.a | n.a | n.a | n.a | 9918 |
| Germany, F.R. | 99.6 | n.a | n.a | n.a | 99.1 | n.a | n.a | n.a | 10708 |
| Italy | n.a | 99.9 | n.a | n.a | n.a | n.a | n.a | n.a | 7425 |
| Portugal | n.a | 99.3 | n.a | n.a | n.a | n.a | n.a | n.a | 3729 |
| Spain | n.a | 99.9 | 99.9 | n.a | n.a | n.a | n.a | n.a | 6437 |
| U.K. | n.a | n.a | 90.5 | n.a | n.a | n.a | n.a | n.a | 8665 |
| Austria | n.a | n.a | n.a | n.a | n.a | n.a | n.a | n.a | 9713 |
| Sweden | 91.7 | n.a | 91.1 | n.a | n.a | n.a | n.a | n.a | 9904 |
| Switzerland | n.a | n.a | n.a | n.a | n.a | n.a | n.a | n.a | 10640 |
| Poland | 96.8 | n.a | 73.9 | n.a | n.a | n.a | n.a | n.a | 4913 |
| Turkey | 76.5 | n.a | 93.8 | n.a | n.a | n.a | n.a | n.a | 2533 |
| No. of observations | 21 | 24 | 23 | 13 | 13 | 13 | 15 | 11 | |
| Mean | 67.7 | 69.1 | 72.7 | 69.8 | 75.6 | 69.0 | 67.4 | 65.1 | |
| Correlation coefficient (share of shuttleless looms/RGDP1) | 0.51 | 0.49 | 0.54 | 0.44 | 0.44 | 0.60 | 0.55 | 0.50 | |

Note: a. In US$ at 1980 international prices.

Source: International Manufacturers Federation, *International Textile Machinery Shipments Statistics*, various issues; Heston, Summers (1988); own calculations.

## Table 3 The International Diffusion of Open-end Rotors - Regression Results

| | $\beta_1$ | $\beta_2$ | No. of observations | $\overline{R}^2$ | LM-test for first-order serial auto-correlation[b] | White test for heteroskedasticity (chi-squared test statistic) |
|---|---|---|---|---|---|---|
| **70 per cent saturation level** | | | | | | |
| (6) | .213 E-03$^{***}$<br>(2.95) | - .233 E-05<br>(- .50) | 394 | .14 | 9.81$^{***}$ | 23.5$^{***}$ |
| (3) | | | 394 | .47 | 2.08$^{**}$ | 91.6 |
| (4) | .157 E-03$^{**}$<br>(2.10) | | 35 | .09 | - | .87 |
| (5) | | .266 E-05<br>( .54) | 35 | - .02 | - | .02 |
| Semi-loglinear model: | | | | | | |
| (4) | .677$^{**}$<br>(2.16) | | 35 | .10 | - | 1.79 |
| (5) | | .752 E-02<br>( .36) | 35 | - .03 | - | .52 |
| **100 per cent saturation level** | | | | | | |
| (6) | .206 E-03$^{**}$<br>(3.09) | - .252 E-05<br>(- .58) | 446 | .13 | 11.43$^{***}$ | 13.3$^{***}$ |
| (3) | | | 446 | .48 | 3.24$^{***}$ | 116.3 |
| (4) | .132 E-03<br>(1.64)[a] | | 36 | .04 | - | 5.63$^{**}$ |
| (5) | | .321 E-05<br>( .68)[a] | 36 | - .02 | - | 4.86$^{**}$ |
| Semi-loglinear model: | | | | | | |
| (4) | .48<br>(1.04)[a] | | 36 | .02 | - | 10.7$^{***}$ |
| (5) | | .02<br>( .67)[a] | 36 | - .01 | - | 10.5$^{***}$ |

Notes: t-statistics in parentheses (two-tailed test).

*** (**; *) Significant at the 1 per cent (5; 10 per cent) confidence level.

a. Standard errors adjusted for heteroskedasticity of unknown form (White, 1980).

b. t-statistic for coefficient of lagged residual in a regression of the estimated residuals on all explanatory variables plus the lagged residual (MacKinnon, 1992, pp. 111).

Source: Data cf. Table 1; own calculations with TSP Version 4.2 software.

## Table 4 The International Diffusion of Shuttleless Looms – Regression Results

| | $\beta_1$ | $\beta_2$ | No. of observations | $\overline{R}^2$ | LM-test for first-order serial auto-correlation[b] | White test for heteroskedasticity (chi-squared test statistic) |
|---|---|---|---|---|---|---|
| (6) | .192 E-03$^{***}$<br>(2.62) | .166 E-04$^{***}$<br>(2.72) | 361 | .39 | 11.73$^{***}$ | 14.37$^{***}$ |
| (3) | | | 361 | .71 | 1.31 | 130.9$^{*}$ |
| (4) | .378 E-03$^{***}$<br>(2.81)[a] | | 37 | .15 | – | 4.08$^{**}$ |
| (5) | | .375 E-05<br>( .38) | 37 | - .02 | – | .37 |
| Semi-loglinear model: | | | | | | |
| (4) | 1.78$^{**}$<br>(2.36)[a] | | 37 | .20 | – | 8.7$^{***}$ |
| (5) | | .022<br>( .52) | 37 | - .02 | – | .47 |

Notes: t-statistics in parentheses (two-tailed test).

*** (**; *) significant at the 1 per cent (5; 10 per cent) confidence level.

a. Standard errors adjusted for heteroskedasticity of unknown form (White, 1980).

b. t-statistic for coefficient of lagged residual in a regression of the estimated residuals on all explanatory variables plus the lagged residual (Mackinnon, 1992, pp. 111).

Source: Data cf. Table 2; own calculations with TSP Version 4.2 software.

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