Journal of Development Studies
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/fjds20

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Version of record first published: 29 Mar 2010

To cite this article: Y-c. Chuang (2002): The Trade-Induced Learning Effect on Growth: Cross-Country Evidence, Journal of Development Studies, 39:2, 137-154

To link to this article: http://dx.doi.org/10.1080/00220380412331322781

The Trade-Induced Learning Effect on Growth: Cross-Country Evidence

YIH-CHYI CHUANG

*One of the important trade effects on growth is technology diffusion through learning by doing. Chuang [*1998*] proposed a trade-induced learning theory in which the nature of traded goods and the trading partners are two key factors determining the effectiveness of the trade-induced learning. The former conveys the characteristics that a country can learn; the latter determines the level of technology from which a country can learn. Using cross-country data, this article constructs a set of the trade-induced learning variables by taking into account trading partners and the characteristics of the traded goods and further tests the trade-induced learning hypothesis. The results show that holding other variables constant, trade-induced learning has a positive and significant effect on growth and the estimated effect implies that a one-standard-deviation increase in the trade-induced learning variable is estimated to generate an effect of between 0.4 to 1.0 percentage points on the annual growth rate. A robustness test shows that the trade-induced learning variable passes the extreme-bound analysis and also outperforms other conventional trade variables advocated in the literature.*

I. INTRODUCTION

After the Second World War, some of the developing countries have experienced miraculous economic growth. The so-called Newly-Industrialising Economies (NIEs) such as Taiwan, South Korea, Hong Kong

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The Journal of Development Studies, Vol.39, No.2, December 2002, pp.137–154
PUBLISHED BY FRANK CASS, LONDON

and Singapore have reached annual growth rates of per capita income averaging about seven per cent, much higher than the industrial economies' average of 2.6 per cent for the period 1960–88. One common feature of NIEs was that they all adopted an outward-oriented strategy during this period. Trade seemed to play an important role in their economic development. In his paper 'Making a Miracle', Lucas [*1993*] conjectured that a large volume of trade is essential to a learning-based growth episode in explaining different growth paths for similarly endowed economies. Numerous authors have also reported that countries with outward-oriented polices tend to have greater rates of economic growth than countries with inward-oriented policies [e.g., *Krueger, 1983; Balassa, 1985; Lal and Rajapatirana, 1987; World Development Report, 1987; Harrison, 1991; Dollar, 1992*, among others). A question arises. What is the mechanism that links trade and growth? Through what channel does trade have an effect on growth?

Chuang [*1998*] proposed a growth model of trade-induced learning by doing to address the real growth effect of trade and the evolution of international trade patterns. In the model, trade-induced learning is the instrument of rapid growth for less developed countries. Other things being equal, two conditions are essential in the trade-induced learning theory. First, both exports and imports are equally important sources and mutually reinforced in intensifying the learning process. Moreover, the nature or learning characteristics of these traded goods also influences the effect of learning. Second, openness of trade is a necessary but insufficient condition for rapid growth. With whom one trades, that is, the trading partner, is the key factor in determining technology spillovers and upgrading, as the trading partner determines the technology level from which one can learn. By means of this trade-induced and technology-driven mechanism, trade has real effects on growth.

The aim of the article is to construct a set of trade-induced learning variables based on Chuang's [*1998*] trade-induced learning theory and to test the hypothesis of this trade-induced learning effect on growth by using 'Barro-style' cross-country regression analysis. This article considers in detail several trade measures, measures which take into account some learning characteristics such as the trade-weighted technology/output gap, imports and exports of machinery, and imports and exports of R&D-intensive goods. This analysis also documents a positive correlation between these trade variables in 1960 and the average growth rate from 1960 to 1985.

Moreover, the results show that this correlation survives numerous attempts at elimination, including the elimination from extreme-bound analysis applied by Levine and Renelt [*1992*] as well as the inclusion of investment shares (which Levine and Renelt argue often drives out trade

variables) and other trade openness indicators. The result implies that a one-standard-deviation increase in the trade-induced learning variable is estimated to generate an effect of between 0.4 to 1.0 percentage points on the annual growth rate. Trading with technology-advanced countries promotes technology diffusion, strengthens the learning effect and eventually expedites long run growth.

The rest of the article is organised as follows. In section II, we briefly discuss the trade-induced learning hypothesis and clarify its difference with some recent empirical studies on trade and growth. Section III presents empirical results of cross-country study and the robustness test of the trade-induced learning variable with other conventional trade variables. The conclusions and discussion follow in section IV.

II. THE TRADE-INDUCED LEARNING HYPOTHESIS

The trade-induced learning growth theory emphasises learning through technology diffusion fostered by importing technically sophisticated goods from advanced countries and exporting refined goods of domestic production lines to international markets. There is a trade-induced learning process through both imports and exports. Learning enables a country to produce new goods and, hence, makes possible the exporting of refined goods. Exporting of refined goods, in turn, leads to absorption of new skills and experiences and generates the demand for new technology, which is helpful for further domestic technology upgrading. This effect, in turn, speeds the need to import new technically sophisticated goods to streamline domestic production. Thus, exporting and importing intensify the learning process. This process of trade-induced technology diffusion provides the momentum for enduring growth in the less developed country.

Opening trade is a necessary but insufficient condition to generate rapid learning. There are two underlying key factors affecting the trade-induced learning process: the learning characteristics of traded goods and the trading partner. The former conveys the characteristics that a country can learn; the latter determines the level of technology from which a country can learn. The nature or learning characteristics of these traded goods generate varied influences for potential learning. For example, manufactured goods have more learning potential than agricultural products and electronic products provide more learning potential than food-processing products. Exporting and importing provide the channel to learn, but trading partners determine the technological sophistication that can be learnt. A technologically advanced country gains no learning from trading with a less technologically endowed country. Conversely, a less technologically endowed country can

incur positive learning from a technologically advanced country by opening trade and gaining access to new technologies.

It deserves mentioning that by using cross-country data for the period 1960–85, Lee [*1995*] found that the ratio of imported to locally produced capital goods in the composition of investment has a significant positive effect on per capita income growth rate across countries. De Long and Summers [*1991, 1993*] also found that investment in machinery and equipment has a strong association with long run growth. However, Lee [*1995*] stressed the increase in efficiency of capital accumulation by importing the relatively cheaper capital goods from high-income countries, whereas, trade-induced learning emphasises the mechanism of export-driven importing of sophisticated capital goods in order to streamline local production.

A recent empirical study by Coe, Helpman and Hoffmaister [*1997*] emphasised the technology diffusion through international R&D spillover. They found substantial R&D spillovers from the industrial countries in the North to the developing countries in the South. In their study, foreign R&D capital stock consisted of a weighted average of domestic R&D capital stocks of the industrial countries with which the developing country trades, using bilateral import shares with the industrial countries as weights. However, in the theory of trade-induced learning, one needs not only to consider the technology level of one's trading partners but also the learning characteristics of goods that one traded, which includes both exports as well as imports. This is what we will try to do in the next empirical section to test the hypothesis.

III. CROSS-COUNTRY EVIDENCE

We test the trade-induced learning theory from data of selected countries. The international data are based on data sets of Summers and Heston [*1988*], Barro [*1991*], and Levine and Renelt [*1992*]. A set of trade-induced learning variables is constructed by taking into account the effects of trading partners and learning characteristics. By using 'Barro-style' cross-country growth regression analysis, we then test the growth effect of the trade-induced learning variable together with other trade variables proposed in the literature. The definition of all variables used in the regressions appears in Appendix A.

The Construction and Tests of the Trade-induced Learning Variables

The technology gap: trading partners matter: The technology gap is represented by the difference of technology level between trading country and the home country, in the empirical analysis we use per capita real GDP

as a proxy for a country's technology level.[1] For cross-country comparison, major oil-exporting countries are excluded from the sample as their high per capita real GDP may not well reflect their technology level. The technology gap is then weighted by the degree of openness with the trading country to capture the trade-induced technology diffusion. Due to asymmetric technology spillovers, if the technology gap is positive, then the weight is equal to the trading partners' share of total trade (imports plus exports) to home country's GDP.[2] If the technology gap is non-positive, then the weight is zero. Thus, the trade-induced learning variable (TLi) is constructed as the

$$TL_i = \sum_j \omega_j \left(PCGDP^j - PCGDP^i\right) \tag{1}$$

$$\text{with} \quad \omega_j = \begin{bmatrix} \dfrac{X_{ij} + M_{ij}}{GDP_i} & \text{if} \quad PCGDP^j > PCGDP^i \\ 0 & \text{if} \quad PCGDP^j \le PCGDP^i \end{bmatrix}$$

summation of these weighted technology gaps and is denoted as

where X_{ij}: exports from home country i to foreign country j.
M_{ij}: imports of home country i from country j.
GDP_i: gross domestic product of country i.
$PCGDP_i$: per capita real GDP of country i.

An index of this trade-induced learning-variable is created by dividing the maximum TLi to each country so that TLi is a trade-induced learning index between zero and unity. Because available trade data are limited, a sample of 78 countries is used in the empirical study for the period 1960–85.

The basic regression equation is

$$GR6085 = \alpha_0 + \alpha_1 TL60 + \alpha_2 GDP60 + \alpha_3 PRIM\,60 + \alpha_4 SEC60 + \alpha_5 GOV + \alpha_6 REVCOUP + \varepsilon \tag{2}$$

As in Barro [*1991*], the dependent variable in the regression equations is the average growth rate of per capita GDP between 1960 to 1985 (GR6085), and the independent variables include initial values in 1960 of per capita GDP (GDP60), human capital proxies (primary and secondary school enrollment rates PRIM60 and SEC60),[3] the share of government consumption in GDP (GOV), and a measure of political stability (number of revolutions and coups per year, ROVCOUP). Variables GOV and REVCOUP are used to capture some country-specific characteristics. Dummies for sub-Saharan African or Latin American (AFRICA and LAAMER) are used in some regressions. Finally, the trade-induced learning index for 1960 (TL60) is included to test the trade effect in growth.

TABLE 1
REGRESSIONS FOR PER CAPITA GROWTH: TEST OF TRADE-INDUCED LEARNING EFFECT ON GROWTH

Dep. Var	GR6085	GR6085	GR6085	GR6085	GR6085	GR6085
No. Obs.	78	78	37*	59	59	59
Constant	0.0261	0.0215	0.2610	0.0353	0.0274	0.0284
	(0.0082)	(0.0071)	(0.0114)	(0.0077)	(0.0085)	(0.0086)
GDP60	-0.0080	-0.0065	-0.0141	-0.0064	-0.0091	-0.0091
	(0.0015)	(0.0014)	(0.0036)	(0.0019)	(0.0016)	(0.0016)
PRIM60	0.0265	0.0226	0.0518	0.0199	0.0229	0.0236
	(0.0060)	(0.0060)	(0.0136)	(0.0064)	(0.0068)	(0.0070)
SEC60	0.0475	0.0483	0.0208	0.0376	0.0566	0.0566
	(0.0122)	(0.0112)	(0.0325)	(0.0147)	(0.0109)	(0.0113)
GOV	-0.0925	-0.0964	-0.0958	-0.1530	-0.1178	-0.1199
	(0.0271)	(0.0240)	(0.0443)	(0.0255)	(0.0279)	(0.0293)
REVCOUP	-0.0223	-0.0205	-0.0161	-0.0186	-0.0217	-0.0219
	(0.0060)	(0.0055)	(0.0060)	(0.0055)	(0.0046)	(0.0050)
TL60		0.0182	0.0283			
		(0.0070)	(0.0072)			
TLMF70				0.0083		
				(0.0023)		
TLRDW					0.4715	
					(0.1127)	
TLCLUW						0.1473
						(0.0388)
Adj. R-Square	0.5628	0.5901	0.4545	0.6855	0.7374	0.7281

Notes: * are samples excluding Sub-Saharan Africa and OECD countries.
See Appendix A for the definitions of variables.
Numbers in parentheses are heteroskedasticity-consistent standard errors.

Table 1 presents the results of regression. As expected, the estimated coefficient on the initial trade-induced learning index, TL60, is positive and significant: 0.0182, s.e.=0.0070.[4] The sample is further limited to countries excluding sub-Saharan Africa countries and OECD countries. The estimated coefficient on TL60 is positive and highly significant: 0.0283, s.e=0.0072. This result implies that the trade-induced learning effect on economic growth was more significant for middle-income and newly industrialising countries. In general, all estimated coefficients of other independent variables are significant and have the same signs as obtained by Barro (1991).

The empirical results indicate that trade-induced learning has a positive and significant effect on growth. The estimated effect implies, for the 1960–85 period, that a one-standard-deviation increase in the trade-induced learning variable (by 0.22 in the 1960) raises the growth rate by 0.4 percentage points per year, and the number is 0.7 percentage points for the middle-income countries. Other things being equal, the more a country

trades with other countries that have higher technology levels, the higher is the subsequent rate of long run growth for the country.

The effective openness: learning characteristics of traded goods: As the nature or learning characteristics of the commodities and trading partners matter in the trade-induced learning process, in this subsection we refine and improve upon this trade-induced learning variable by considering the trade of manufactured goods as they contain more learning potential than agriculture products. More disaggregated manufactured goods are also examined.

For simplicity and without loss of the essence of the model, the construction of all trade-induced learning variables is concentrated on the imports and exports of each country with OECD countries to feature the trading partner's effect. For each country, the relevant trade variable is constructed by taking the value of manufactured goods (SITC 5 to 8 excluding 68) exported to OECD countries plus the electrical and non-electrical machinery (SITC 71 and 72) imported from OECD countries as a share of the country's manufacturing value added (MVA). The reason to use MVA instead of GDP is to eliminate the influences of the agricultural sector that seems to have little dynamic learning involved.

Because of limited data, the new trade-induced learning variable (TLMF70) is calculated using 1970 data, and the sample contains 59 countries. The result in Table 1 shows that the trade-induced learning variable, TLMF70, is positive and significant: 0.0083 s.e. = 0.0023.[5] The estimated effects imply that a one-standard-deviation increase in the TLMF70 variable is estimated to increase the growth rate by 0.35 percentage points per year.

In order to investigate carefully the effect of learning characteristics, examination of more disaggregated manufactured goods is required. Two definitions of learning characteristics are then used. First, the learning characteristics of the trading commodities are defined according to their R&D intensity. As R&D intensity is a proxy for the level of technology, goods with greater R&D intensity exhibit greater learning. Aho and Rosen [*1980*] selected high-technology goods from 74 SITC three-digit commodities according to their R&D intensity from US data.[6]

Based on these commodities, the trade variable (TLRDW), the share of total trade (imports plus exports) of these commodities in total manufacturing value added weighted by their corresponding R&D intensity, is constructed by using 1970 data. The coefficient of TLRDW is positive and significant: 0.4715, s.e. = 0.1127. The result implies that a one-standard-deviation increase in the TLRDW variable raises the growth rate by 0.97 percentage points per year.

Alternatively, Leamer [*1984*] constructed nine clusters of commodities based on SITC two-digit commodities; the manufactured goods were decomposed into four clusters: labor-intensive, capital-intensive, machinery, and chemical products. Therefore, the second learning characteristics of the traded goods are considered by weighting these four clusters of manufacturing goods with the corresponding skill ratios of scientists and engineers found in Hufbauer [1970].[7] The coefficient of this new trade variable, TLCLUW, is also positive and highly significant: 0.1473, s.e.= 0.0388. The result means that a one-standard-deviation increase in the TLCLUW variable is estimated to increase the growth rate by 0.4 percentage points per year.

In general, a stable positive growth effect of the trade-induced learning is found and, the effect is especially significant for the middle-income group of countries. Further consideration of the commodity's learning characteristics reconfirms the previous finding of the trade-induced learning effect on growth.

Test of export and import effect separately: In the trade-induced learning process, both exports and imports are important sources and have a tendency to reinforce each other's learning. In this subsection, the export and import effect is tested separately. The ratio of total exported manufactured goods to OECD countries to the country's manufacturing value added is taken to measure the export effect (EXMF70), whereas the ratio of imported electrical and non-electrical machinery from OECD countries to manufacturing value added is taken as a measure of the import effect (IMMF70). Table 2 presents the estimation results. The import measure is positive and significant, whereas the export measure is also positive but less significant. When we further restrict exported manufactured goods to machinery and equipment only. The export measure is positive and significant but the import measure is positive and insignificant.

As the nature of the commodities influences the effectiveness of learning, individual import and export effects are explored by using import (IMRDW and IMCLUW) and export (EXRDW and IMCLUW) measures of the above learning characteristics. The results are positive and significant: 0.2591, s.e.= 0.1512 for EXRDW; 0.0971, s.e.= 0.0524 for IMCLUW; 0.5588, s.e= 0.2044 for EXCLUW. The coefficient of exports is more significant without two regional dummies, whereas the coefficient of imports is more significant with two regional dummies.

The preliminary results indicate that the growth effect of imports and exports coexists. However, as discussed in Chuang [*1998*], the existence of mutual reinforcement between exports and imports in the learning process may lead to the situation in which it is difficult to test separately the learning

TABLE 2
TEST OF IMPORT vs. EXPORT EFFECTS

Dep. Var No. Obs.	GR6085 59	GR6085 48	GR6085 59	GR6085 59	GR6085 59	GR6085 59
EXMF70	0.0063	0.0688*				
	(0.0044)	(0.0191)				
IMMF70	0.0096	0.0024				
	(0.0033)	(0.0042)				
IMRDW			0.2591	0.3908		
			(0.1512)	(0.1454)		
EXRDW			2.0157	1.2853		
			(0.4800)	(0.4948)		
IMCLUW					0.0971	0.1453
					(0.0524)	(0.0464)
EXCLUW					0.5588	0.2878
					(0.2044)	(0.1824)
AFRICA				-0.0142		-0.0157
				(0.0040)		(0.0039)
LAAMER				-0.0106		-0.0118
				(0.0039)		(0.0039)
Adj. R-Square	0.6806	0.6052	0.7632	0.7959	0.7401	0.7825

Notes: GDP60, PRIM60, SEC60, GOV, REVCOUP included in all the regressions.
* The export measure contains machinery and equipment only.
See notes in Table 1 for additional information.

effect generated jointly by these two important sources. The above tests, nevertheless, confirm the proposition that both imports and exports are important sources in intensifying the learning process and, hence, affect long-run growth.

Robustness Test

Many researchers have found a positive effect of trade performance on growth. However, Levine and Renelt [*1992*] used extreme-bound analysis (EBA) for the sensitivity analysis to reexamine the relationship between trade and growth. Their main findings follow.

> First, if one substitutes imports or total trade for exports in cross-country growth or investment regression one obtains essentially the same coefficient estimates and standard errors … Second, the share of trade in GDP is robustly positively correlated with the share of investment in GDP. Finally, when controlling for the share of investment in GDP, we could not find a robust independent relationship between any trade or international price-distortion indicator and growth. These three results indicate that an important part of the relationship between trade and growth may be based on enhanced resource accumulation and not necessarily on the improved allocation of resources.

The first finding seems to support the trade-induced learning theory that not just exports or imports but both are important to intensify trade-induced learning as confirmed in the preceding section. Nevertheless, in order to distinguish the effect of a trade-induced learning measure from that of ordinary trade measures, we first test the trade-induced learning effect alongside other trade orientation variables. Next, we use Leamer's extreme-bound analysis to test for the robustness of the trade-induced learning variable.

Test with Other Trade Orientation Variables

The theory proposes that opening trade is only a necessary but not sufficient condition for promoting long-run growth, and further emphasises the learning characteristics of traded goods and trading partners. In the preceding section, the variable TLMF70 was constructed by focusing on manufactured goods and on trade with OECD countries. Thus in this subsection, joint tests were made between the trade-induced learning variable TLMF70 and the following trade variables proposed in recent papers:

(1) Trade intensity ratio, OPEN70: total trade as share of GDP [*Quah and Rauch, 1990*];
(2) Adjusted trade intensity ratio (overall and manufacturing sector only), LEAMALL and LEAMMF: measuring the deviation between actual and predicted trade [*Leamer, 1988*];
(3) International intervention: distortion and variability of the real exchange rate from the hypothetical free trade level, EXCHDIST and EXCHVAR [*Dollar, 1992*]; deviation of the black-market rate from the official exchange rate, black market exchange rate premium BMP [*Levine and Zervos, 1993*];
(4) An orientation index, ORI [*World Development Report, 1987; Dollars, 1992; James and Romijn, 1997*].

These trade variables are included as additional independent variables one at a time in the regression equation. The results are shown in Table 3. In all scenarios, the trade-induced learning variable stands and remains positive and highly significant: 0.0054-0.0102, s.e.=0.0014-0.0028. Most trade variables are positive and significant but become insignificant when two regional dummies are added, except the variable ORI. Including two regional dummies significantly diminishes the magnitude of all other trade variables except for the trade-induced learning variable TLMF70. In order to test the fragility of these trade variables mainly due to the large correlation between the trade variable and investment, as argued by Levine

TABLE 3
TEST WITH OTHER TRADE ORITATION VARIABLES

Dep. Var	GR6085	GR6085	GR6085	GR6085	GR6085	GR6085	GR6085	GR6085	GR6085	GR6085	GR6085	GR6085
No. Obs.	59	34	34	34	34	59	59	51	44	44	43	43
TLMF70	0.0061	0.0063	0.0077	0.0057	0.0072	0.0087	0.0086	0.0074	0.0095	0.0102	0.0056	0.0063
	(0.0027)	(0.0014)	(0.0017)	(0.0019)	(0.0021)	(0.0025)	(0.0023)	(0.0033)	(0.0026)	(0.0027)	(0.0008)	(0.0025)
OPEN70	0.0620											
	(0.0048)											
LEAMALL		0.0171	0.0058									
		(0.0086)	(0.0105)									
LEAMMF				0.034	0.015							
				(0.0167)	(0.0182)							
EXCHDIST						-0.00005	-0.00001					
						(0.00003)	(0.00004)					
EXCHVAR						-0.0269	-0.0152					
						(0.0145)	(0.0099)					
BMP								-0.0063				
								(0.0108)				
ORI									-0.0051	-0.0028		
									(0.0017)	(0.0014)		
EQUIPSH											0.1705	0.0063
											(0.0910)	(0.0943)
AFRICA			-0.0039		-0.0037		-0.0142			-0.0148		-0.0138
			(0.0039)		(0.0037)		(0.0040)			(0.0035)		(0.0058)
LAAMER			-0.0180		-0.0090		-0.0158			-0.0125		-0.0163
			(0.0045)		(0.0041)		(0.0042)			(0.0040)		(0.0051)
AdJ. R-Square	0.6859	0.7599	0.7443	0.7405	0.7614	0.7033	0.7722	0.6470	0.7573	0.7968	0.7033	0.6524

Notes: GDP60, PRIM60, SEC60, GOV, REVCOUP included in all the regressions.
See notes in Table 1.

TABLE 4
RESOURCE ACCUMULATION vs. EFFICIENT ALLOCATION

Dep. Var	GR6085	GR6085	GR6085	GR6085	GR6085	GR6085	GR6085	GR6085	GR6085	GR6085	GR6085	GR6085	GR6085
No. Obs.	59	59	34	34	34	34	59	59	51	44	44	43	43
INV	0.0406	0.0381	0.0432	0.0509	0.056	0.058	0.0341	0.0382	0.0493	0.0986	0.092	0.0109	0.0363
	(0.0263)	(0.0256)	(0.0277)	(0.0300)	(0.0285)	(0.0310)	(0.0272)	(0.0234)	(0.0286)	(0.0279)	(0.0224)	(0.0339)	(0.0311)
TLMF70	0.0073	0.0054	0.0057	0.0071	0.0043	0.0058	0.0080	0.0077	0.0058	0.0070	0.0079	0.0055	0.0061
	(0.0024)	(0.0027)	(0.0013)	(0.0013)	(0.0017)	(0.0020)	(0.0024)	(0.0021)	(0.0026)	(0.0021)	(0.0020)	(0.0008)	(0.0025)
OPEN70		0.0056											
		(0.0044)											
LEAMALL			0.0178	0.0055									
			(0.0081)	(0.0096)									
LEAMMF					0.0428	0.0237							
					(0.0176)	(0.0195)							
EXCHDIST							-0.00005	-0.00002					
							(0.00003)	(0.00003)					
EXCHVAR							-0.0218	-0.0086					
							(0.0147)	(0.0111)					
BMP									-0.0063				
									(0.0103)				
ORI										-0.0046	-0.0025		
										(0.0015)	(0.0013)		
EQUIPSH												0.1642	0.0408
												(0.0912)	(0.0910)
AFRICA				-0.0046		-0.0037		-0.0137			-0.0140		-0.0144
				(0.0039)		(0.0042)		(0.0040)			(0.0037)		(0.0062)
LAAMER				-0.0098		-0.0092		-0.0161			-0.0116		-0.0170
				(0.0037)		(0.0035)		(0.0042)			(0.0033)		(0.0048)
Adj. R-Square	0.6903	0.6894	0.7504	0.7739	0.7561	0.7614	0.7046	0.7768	0.6550	0.7968	0.8332	0.5121	0.5117

Notes: GDP60, PRIM60, SEC60, GOV, REVCOUP included in all the regressions.
See notes in Table 1.

and Renelt (1992), an additional variable investment share (INV) is included in every regression. The results are shown in Table 4.

Including variable INV does not affect the trade-induced learning variable. However, by including investment share (INV), trade variables, OPEN70, EXCHDIST and EXCHVAR become insignificant, whereas LEAMALL and LEAMMF become insignificant with two regional dummies included. Only the ORI variable remains significant. In all conditions the trade-induced learning variable, TLMF70, is positive and significant. Therefore, the trade-induced learning variable is more robust than other open-trade variables in explaining cross-country per-capita growth differentials. These results corroborate the theory that opening trade is only a necessary but insufficient condition for long run growth. Trading partners and the nature of traded goods are key factors determining trade-induced learning and long-run growth.

De Long and Summers [*1991, 1993*] found that investment in machinery and equipment has a strong association with long run growth. Hence, the trade-induced learning variable is further tested by including the equipment-share variable, EQUIPSH. From Table 4 and Table 5, adding two regional dummies or an investment-share variable significantly affects the significance of the coefficient of the equipment-share variable (EQUIPSH), whereas the trade-induced learning variable remains positive and significant.

This result further indicates that merely increasing or accumulating the investment of equipment and machinery cannot ensure long-run growth. Because of a trade-induced learning effect, investment is guided in the right direction, and domestic resource allocation is streamlined. Therefore, the results support the theory of trade-induced learning improving allocation, not just pure resource accumulation.

Extreme-Bound Analysis

Levine and Renelt [*1992*] used Edward Leamer's extreme-bound analysis (EBA) to test the empirical definition of 'unbelievable', and showed that most existing 'empirical facts' are not believable, that is, small alterations in the right-hand-side variables alter the statistical significance of most existing results.

According to their procedures to compensate for the share on investment in GDP, four variables – the average inflation rate (PI), standard deviation of the rate of inflation (STPI), growth rate of domestic credit (GDC), and the ratio of liquid liabilities to GDP (LLY)[8] – are chosen as additional variables (their Z-variables) to perform the EBA. EBA is done by including diverse combinations of these four variables in the regression equation one at a time and calculating the extreme upper bound, the largest calculated

TABLE 5
SENSITIVITY RESULTS FOR TRADE-INDUCED TECHNOLOGY DIFFUSION VARIABLE

DEPENDENT VARIABLE: GR6085
TEST VARIABLE: TDMF70

	Beta	Standard Error	t-Statistic	Countries	Adj. R^2	Other Variable
HIGH	0.008	0.003	2.6667	57	0.7513	LLY, PI
BASE	0.0075	0.0021	3.5714	59	0.7827	
LOW	0.0073	0.0032	2.2813	55	0.7512	LLY, PI, GDC, STPI

Notes: GDP60, PRIM60, SEC60, GOV, REVCOUP, INV, AFRICA, AND LAAMER are included in all regressions.
The high beta is the estimated coefficient from the regression with the extreme upper bound (β_m+2* standard deviation).
The low beta is the estimated coefficient from the regression with the extreme lower bound (β_m–2* standard deviation).

value of β_m+2* standard deviation and the extreme lower bound, the lowest calculated value of β_m–2* standard deviation. The results of EBA appear in Table 5. The trade-induced learning variable, TLMF70, passes the EBA test. Therefore, the trade-induced learning variable shows a robust positive correlation with long-run growth.

IV. DISCUSSION AND CONCLUSION

In the trade-induced learning process, the nature of traded goods and trading partners are two key factors that determine the effectiveness of trade-induced learning. The former conveys the characteristics that a country is able to learn; the latter determines the technology level from which a country can learn. In contrast to ordinary trade variables, this analysis constructs a set of trade-induced learning variables by incorporating the learning characteristics of traded goods and the effect of trading partners. By using cross-country data, we then test the trade-induced learning hypothesis and perform robustness testing of the trade-induced learning effect on long run growth. We conclude from the regression results that the trade-induced learning effect on long-run growth is positive and significant. Opening trade creates opportunities to gain access to new technologies, but this condition is only necessary, not sufficient, especially for a less advanced country to facilitate long-run growth. Trade with technology-advanced countries promotes and strengthens the learning effect and eventually expedites long-run growth.

The general problem of causality is relatively minor in this study as only traded goods in a subset are taken, especially trade with a particular group of

countries, for example, OECD countries. Furthermore, the trade-induced learning variables were constructed at an initial year (1960) of the sample period 1960–85. It is less plausible to argue that the causality operates in reverse, for example, long run average growth affects the value of initial trade. When this trade-induced learning process exists, a conventional measure of comparative advantage, for example, RCA index, using net export data (export minus imports), might be misleading as it neglects the interactive effect that exists between imports and exports. The traditional trade intensity (total trade share in GDP) as a measure of the degree of openness generally involves the problem of the need for structure-or factor-adjustment.[9] Here, as the measure focuses on a particular group of trading commodities by considering both the learning characteristics of the goods and the effects of trading partners, the above adjustment problem might be negligible.

In the empirical study we have attempted to distinguish between the trade-induced variables and other conventional trade variables. The results seem to support a possible channel of trade effect on growth. However, we needed to be cautious in the interpretation of the regression results as we may not be able to fully control country-specific characteristics and other effects such as those of technological backwardness or initial specialisation in manufacturing.[10] As the learning characteristics of trade goods matter, intuitively machinery contains more perceivable and reliable information than other manufactured goods for learning and imitation (for example, reverse engineering). Therefore, collecting micro-data of specific-industry (for example, electrical machinery, office machines, telecommunication equipment, etc.) from countries like NIEs to analyse and to identify the trade-induced learning effect on the evolution and development path of the industry would further help in understanding the mechanism of the learning process as a source of long run growth.

final revision accepted December 2001

NOTES

1. The following are possible proxies for a country's technology level: (a) per capita real GDP; (b) labor productivity in the manufacturing sector; (c) total factor productivity; (d) number of patents by sector; (e) scientists and engineers as a fraction of total employment, and (f) R&D intensity.
2. Using trade intensity (that is, the ratio of trade to total output) as a proxy to measure the openness is sometimes accompanied by adjustments, either correcting for certain structural characteristics (for example, level of per capita GDP, country size) or for differences in factor endowments across countries. The former is call 'structure-adjusted trade intensity ratio' and the latter 'endowment-adjusted trade intensity ratio'. Pritchett [*1991*] found that the endowment-adjusted measure has a much greater correlation with the unadjusted than the structure trade intensity ratio. For various measures of openness and their relationships see Pritchett [*1991*]. This work was confined to the unadjusted trade ratio; later an 'effective'

openness is constructed by taking learning characteristics of traded goods into consideration.

3. Of course, there are other human capital proxies, for example, the average years of education (see Barro and Lee [*1993*]). We have tried other proxies, however, the use of other human capital variables does not significantly change our estimation results on the trade-induced learning variable. As the main purpose of the paper is not to distinguish different types of human capital and their effects on growth, hence we only show one of the specifications for human capital.
4. We also perform the analysis by dividing the sample into two subsample periods, 1960–73 and 1973–98, and it does not change the main results. After adding two regional dummies, the estimated coefficients of the trade-induced learning variable become even stronger and more significant.
5. When the sample is further confined to non-OECD countries or countries with per capita GDP in 1960 between $600 and $2,000, the coefficients of the trade-induced learning variable are still positive and highly significant.
6. The R&D intensity is defined as the ratio of R&D expenditure to the value of product shipments.
7. Hufbauer [*1970*] defined skill ratios as the fraction of the industry's labour force accounted for, in USA, by professional, technical and scientific personnel. In their cross-country analysis, James and Romijn [*1997*] also stressed the measure of technological capability to the skilled complexity involved in the manufacture of engineering goods.
8. There are no precise criteria on how many variables should be included in extreme-bound Analysis. For comparison, we choose the variables used by Levine and Renelt [*1992*] and Levine and Zervos [*1993*] in their sensitivity analysis to perform the EBA test for the trade effect on growth.
9. See note 2.
10. I thank one referee for pointing out this possible restriction.

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APPENDIX A
DEFINITIONS OF VARIABLES

AFRICA: dummy variable for sub-Saharan African countries, Barro [*1991*].
BMP: black-market exchange-rate premium, Levine and Zervos [*1993*].
EQUIPSH: equipment share, De long and Summers [*1991*].
EXMF70 (IMMF70): ratio of manufactures exports (imports) to MVA in 1970.
EXCHDIST: exchange-rate distortion measure, Dollar [*1992*].
EXCHVAR: exchange-rate variation measure, Dollar [*1992*].
EXCLUW (IMCLUM): ratio of exports (imports) of manufactured goods to MVA in 1970 weighted by skill ratio.
EXRDW (IMRDW): ratio of exports (imports) of 74 technology goods to MVA in 1970.
GDC: growth rate of domestic credit, Levine and Renelt [*1992*].
GDP60: real per capita GDP in 1960 (1980 base year), Barro [*1991*].
GOV: ratio of real government consumption to real GDP, Barro [*1991*].
GR6085: average annual growth rate of real per capita GDP from 1960 to 1985, Barro [*1991*].
INV: ratio of real domestic investment to real GDP, Barro [*1991*].
LAAMER: dummy variable for Latin American countries, Barro [*1991*].
LEAMALL (LEAMMF): overall (manufacturing only) openness measure, Leamer [*1988*].
OPEN70: ratio of total trade (imports plus exports) to GDP in 1970, Barro [*1991*].
ORI: orientation index, Dallor [*1992*].
PI: average inflation rate, Levine and Renelt [*1992*].
PRIM60: 1960 primary-school enrollment rate, Barro [*1991*].
REVCOUP: number of revolutions and coups per year, Barro [*1991*].
SEC60: 1960 secondary-school enrollment rate, Barro [*1991*].
STPI: standard deviation of average inflation rate, Levine and Renelt [*1992*].
TL60: 1960 value of trade-induced technology diffusion index.
TLCLUW: ratio of total trade manufactured goods to MVA weighted by the corresponding skill ratio.
TLMF70: ratio of manufactures exports plus machinery imports to MVA in 1970.
TLRDW: ratio of total trade of 74 technology goods to MVA in 1970 weighted by the corresponding R&D intensity.