AN ABSTRACT OF THE DISSERTATION OF

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Technology is a key determinant of comparative advantage among nations. As information technology improves and the nations of the world become economically integrated, concern arises over the dissipation of high-income economies' technological advantage. The three essays in this dissertation explore the trade and technology relationship, which is essential to economic growth in both high- and low-income nations.

The first essay employs a monopolistic competition framework to investigate the effects – on each country's relative wages, share of global markets, and welfare – of the productivity convergence between a technological leader and follower. Results indicate technological convergence improves the follower's competitiveness at the expense of the leader's. Nevertheless, the leader's welfare improves unambiguously on account of the increase in its terms of trade, while the follower's welfare changes in a direction depending on the relative strength of convergence's income and terms-of-trade effects. We use data from 17 food industries in 30 countries, 1993-2001, to test these analytical predictions. Convergence has lifted followers' income and global value-added share.

Followers' welfare has risen since convergence's income improvement has outweighed its terms-of-trade deterioration. Simultaneously, leaders' welfare has improved in response to their improved terms of trade.

The second essay employs data from 35 countries in 128 ISIC 4-digit manufacturing industries, 1993 - 2001, to test the empirical validity of these same hypotheses for the international manufacturing sector. We find that, just as in the food sector, convergence improves followers' welfare through its positive income effects. However, we do not find empirical evidence of convergence's terms-of-trade effects.

The third essay examines trade liberalization's effects on the geographical distribution of productivity, and consequent cross-country resource and market-share allocations, of five processed food industries. We find that the mean and other quantiles of the global productivity distribution shift to the right as international trade liberalizes. The latter result implies that resources are reallocated toward countries with faster productivity growth.

The three essays jointly highlight the important influence of global integration and technological convergence on nations' economic growth and well-being. However, policies promoting integration and convergence should pay attention to the consequent intra-country redistribution of income between producers and consumers.

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by

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Jun Ruan, Author

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CONTRIBUTION OF AUTHORS

Dr. Munisamy Gopinath was involved with the design, analysis, and writing of every chapter. Dr. Steven Buccola was involved with the design, analysis, and writing of Chapter 2.

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CHAPTER 1

INTRODUCTION

By addressing the consequences of narrowing cross-country technological or productivity differences, the three essays of this dissertation contribute to the trade and economic growth literature. Industrialized or high-income economies are apprehensive about the dissipation of their productivity advantage over emerging economies in light of recent advances in information technology and multilateral economic integration. For instance, Samuelson (2004) argues that if an emerging economy improves technology in its export industries, all countries would benefit from the global output rise. Yet if the same improvement is in a good exported from an industrialized country, the latter would lose on account of falling terms of trade. In a response to Samuelson (2004), Bhagwati, Panagariya, and Srinivasan (2004) point out gains from growing intra-industry trade would alleviate the industrialized country's losses from declining terms of trade. The objective of this dissertation is to investigate, analytically and empirically, the effects of global economic integration and technological convergence on the competitiveness, economic growth and welfare of both high- and low-income economies.

Essay 1, presented in Chapter 2, investigates the welfare effects of technological convergence in processed food industries. Since technological change is a key determinant of production and trade patterns, recent evidence of global technological convergence and its consequences have become a subject of debate (Krugman 1990; Wolff and Dollar 1993; Coe and Helpman 1995; Keller 2001; Samuelson 2004; Bhagwati, Panagariya, and Srinivasan 2004). We develop a monopolistic competition framework to investigate the effects – on each country's relative wages, share of global markets, and welfare – of the productivity convergence between a technological leader and follower.

Unlike in previous studies, we decompose technological convergence's effects on welfare into those arising from income and terms of trade for both the leader and follower. Our analytical predictions are then tested using data from the United Nations Industrial Development Organization's (UNIDO) Industrial Statistical Database (INDSTAT4 2005) on 17 food industries in 30 countries, 1993-2001. The disaggregated, 4-digit industry data are in line with our monopolistic competition framework, which embodies intra-industry trade. For empirical purposes, technology is represented by total factor productivity, TFP, which is estimated through a value-added function. We employ a β convergence equation to derive the rate at which cross-country productivity differences are narrowing for each food industry. Then, the effects of convergence on leaders' and followers' relative wages, share of global markets, and welfare are empirically estimated.

Chapter 3 (Essay 2) examines the welfare implications of technological convergence in international manufacturing industries. Since the 1990s, deepening global integration has greatly facilitated technology transfers between high- and low-income economies, speeding followers' technological "catch-up" in manufacturing industries. Many emerging Asian and South American economies now account for a larger and growing share of global markets for manufactured products. Employing the theoretical model developed in Chapter 2, we test the welfare impacts of technological convergence using data on 128 manufacturing industries classified at ISIC (Revision 3) 4-digit levels (INDSTAT4 2005). Again, cross-country and –industry TFP are computed from the estimates of value-added function. Convergence rates and their effects on leaders' and followers' relative wages, share of global markets, and welfare are estimated as in Chapter 2.

Chapter 4 presents Essay 3, which examines the effects of trade liberalization on global productivity distribution and the cross-country reallocation of resources and market shares in 5 processed food industries. Recent research has indicated that in the presence of firm heterogeneity, trade liberalization raises an industry's average productivity by forcing its least productive firms to exit (Melitz 2003; Helpman, Melitz, and Yeaple 2004). At the same time, resources and market shares are reallocated towards more productive firms within the concerned industry. Drawing on the above contributions, we investigate the trade liberalization-productivity distribution linkage in a cross-country setting. The possibility of low-productivity firms' death and resource shifts in favor of high-productivity firms, following trade liberalization, have important consequences for developing countries' employment, wages, and income growth. Our application considers heterogeneity across countries within each processed food industry and tests the hypothesis that the mean of the global productivity distribution shifts to the right following trade liberalization. In addition, we examine the consequent intra-industry redistribution of market shares and resources among countries.

Finally, Chapter 5 provides an overall summary of the results from the three essays followed by conclusions and policy implications.

CHAPTER 2

WELFARE EFFECTS OF TECHNOLOGICAL CONVERGENCE IN PROCESSED FOOD INDUSTRIES

2.1 Introduction

In the past few decades, the composition of global agricultural trade has shifted decidedly toward processed foods. For instance, processed exports rose an average annual 6 percent between 1981 and 2004, compared with an annual 3 percent rise in primary exports. Two-thirds of globally traded agricultural products, with a value above $783 billion in 2004, have in recent years undergone some form of value addition before shipment (International Trade Statistics 2005, WTO; U.S. Department of Agriculture 2005). At the same time, the structure of global food production and consumption has changed significantly. Rapid income growth in emerging markets – for example in Asian countries – has expanded the supply and demand for processed foods, in turn altering the regional composition of global trade. China alone has become the third largest destination for exports and fourth largest source of imports of U.S. processed foods (U.S. Department of Commerce 2006).

The literature on global trade patterns has demonstrated that technology is a key source of comparative advantage in food processing and that technological level and growth vary by country (Trefler 1993; Bernard and Jones 1996a; Harrigan 1997; Chan-Kang, Buccola, and Kerkvliet 1999; Morrison Paul 2000). In the wake of the 1990s globalization wave, a number of analysts have asked whether technological convergence has eroded such comparative advantage (Baumol, Nelson, and Wolff 1994; Coe and Helpman 1995; Bernard and Jones 1996b; Keller 2001; Gopinath 2003). Indeed, the nature and rate of technological convergence between high- and low-income economies, and its consequence for both leaders and followers, have become the core of a new literature (Krugman 1990; Coe, Helpman, and Hoffmaister 1997; Keller 2001; Samuelson 2004; Bhagwati, Panagariya, and Srinivasan 2004).

Yet convergence's welfare impacts, and production and trade consequences, have remained contentious. Krugman's (1990) technology-gap model suggests that when a follower catches up with a leader, the follower's real wages rise but the leader's welfare may decline through terms-of-trade effects. Samuelson (2004) argues that if a less-developed country improves technology in its export industries, all countries benefit from the global output rise. Yet if the same improvement is in a good exported from an advanced country, the latter loses on account of falling terms of trade. These analyses, however, are limited to the traditional, inter-industry trade context. In a response to Samuelson (2004), Bhagwati, Panagariya, and Srinivasan (2004) point out gains from growing intra-industry trade would alleviate the advanced country's losses due to declining trade terms.

The objective of the present article is to analyze technological convergence and its consequences for processed food industries in the presence of intra-industry trade. Indeed global trade including processed foods is increasingly intra-industry in nature, where Krugman's (1980) monopolistic competition model has been the basis of extensive gravity-type modeling of trade structure and patterns (Anderson and van Wincoop 2003; Feenstra 2004). We extend Krugman's (1980) monopolistic competition setting to model technological convergence as the source of narrowing inter-country gap in fixed or marginal costs of production. Our comparative statics results suggest convergence raises the follower's relative wage and global production share, a result consistent with

Samuelson's (2004) claim. However, convergence also improves the leader's terms-of-trade, unambiguously improving its welfare. This is consistent with Bhagwati, Panagariya, and Srinivasan's argument that leaders can benefit from technological convergence when trade is intra-industry. Unlike in previous studies, the follower's welfare depends on the relative strength of its technology enhancement and terms-of-trade decline.

Our empirical analysis includes 1993-2001 data from 30 countries (10 high-income, 20 low-income) on 17 processed food industries, defined on the basis of ISIC (Revision 3) 4-digit classification. We employ a value-added function allowing for country-, industry-, and time-specific effects to estimate total factor productivity (TFP) levels and growth rates, assuming variable returns to scale (Harrigan 1999). Technological or productivity convergence is identified by regressing TFP growth rates on initial TFP levels (β convergence) in each food industry (Bernard and Jones 1996a). We then estimate welfare impacts of productivity convergence, including effects on the follower's global value-added share, relative wage, imported share of consumption, and welfare of both leader and follower. To our knowledge, this is the first study of the welfare implications of cross-country TFP convergence in disaggregated (ISIC 4-digit) food industries.

2.2 Conceptual Framework

Our economic setting considers two countries, A and B, each of which produces a series of differentiated goods under monopolistic competition (Krugman 1980). Labor is the only input in production, which involves fixed (α) and variable (β) costs. Technology is expressed in unit labor requirements: $l_i = \alpha + \beta x_i$, where x_i denotes the output of the i^{th} good. As in Krugman's (1980) framework, an asterisk denotes the corresponding variable in country *B*. For example, country *B*'s technology is given by $l_i^* = \alpha^* + \beta^* x_i^*$. International trade is costless, and consumers in either country consume all varieties produced by both countries.

The representative consumer's utility takes a CES form over a number of goods: $U = \sum_{i=1}^{n+n^*} c_i^{\theta}$, $0 < \theta < 1$, denotes the elasticity of substitution, c_i is consumption of the i^{th} good, and *n* (n^*) is the number of goods in country *A* (*B*). The i^{th} good's demand function is:

$$c_i = \frac{w p_i^{1/(\theta-1)}}{\sum_{i=1}^{n+n^*} p_i^{\theta/(\theta-1)}}, \tag{2.1}$$

where w and p_i denote country *A*'s wage rate and the price of the i^{th} good, respectively.

Consistent with monopolistic competition, each firm produces a unique good in equilibrium. Profit maximization implies all firms charge a price equal to a constant markup over marginal cost ($p_i = \frac{\beta}{\theta} w$). Consequently, all goods produced within a country have the same price. Free entry leads to zero profit, yielding the equilibrium output of each good:

$$x_i = \frac{\alpha}{(p_i / w - \beta)} = \frac{\alpha\theta}{\beta(1-\theta)}, \qquad i = 1, \ldots, n \tag{2.2}$$

$$x_i^* = \frac{\alpha^*}{(p_i^* / w^* - \beta^*)} = \frac{\alpha^* \theta}{\beta^*(1-\theta)}, \qquad i = n+1, \ldots, n+n^*.$$

Equation (2.2) indicates all goods produced in the same country have identical output. Full labor employment generates the equilibrium number of varieties in each country:

$$(2.3) \qquad n = \frac{L(1-\theta)}{\alpha}, \qquad n^* = \frac{L^*(1-\theta)}{\alpha^*}.$$

Note that country size (L or L^*) positively affects, and fixed cost (α or α^*) negatively affects, the number of varieties (n or n^*). In each country imports equal exports, given by $TR = \frac{wLw^*L^*}{wL + w^*L^*}$, where *TR* denotes trade.

To model technological convergence, we assume country *A* has a technological advantage over country *B*, i.e., $\alpha < \alpha^*, \beta < \beta^*$. Convergence is defined as a narrowing inter-country gap in fixed or marginal production costs, captured by a decline in α^* / α or β^* / β. Alternatively, convergence can be thought of as a narrowing difference between countries *A* and *B* in labor productivity (x / l and x^* / l^*). Our focus below is on marginal cost convergence, holding fixed costs constant.[1] We will refer to country *A* and *B* as leader and follower, respectively. Suppose the leader's marginal cost β is given, while the follower's marginal cost β^* is endogenously determined. In particular, β^* approaches β according to $\beta^* = \beta / (1 - e^{-\lambda})$, where λ is rate of convergence in marginal costs. The faster the technological convergence, the lower is the follower's marginal cost, i.e., $\frac{\partial \beta^*}{\partial \lambda} < 0$. We now outline our key comparative-static results and testable hypotheses. Technical derivations and proofs are in Appendix I.

Our first result pertains to the leader's and follower's global production share. In the presence of technological convergence, the leader's output will remain unchanged because its fixed and marginal costs remain the same. Since labor endowments and fixed costs do not change, the number of varieties in each country remains constant. However, as shown in equation (2.2), the follower's output of each variety increases with the decline in its marginal cost. As a result, the follower's relative supply increases, inducing an expansion in global supply. This is consistent with Krugman (1990) and the arguments of Bhagwati, Panagariya, and Srinivasan (2004).

Result 1. Technological convergence will increase (decrease) the follower's (leader's) global production share.

As Samuelson (2004) noted, a follower's technical progress can lower the leader's relative wage and living standards. We first address the change in the leader's wage rate relative to the follower's. The constant mark-up in each country can be used to derive this relative wage, which depends, as in Krugman (1980), on relative price and relative marginal cost. In our model, however, relative price depends on relative global supply, which in turn depends upon the technological convergence rate. While a one percent increase in follower's relative (labor) productivity brings a one percent increase in relative global supply, the corresponding terms-of-trade changes by less than one percent (equation I.2, appendix I). Convergence therefore has a net positive (negative) effect on the follower's (leader's) relative wage, so that factor prices tend to equalize, a frequent result in traditional and new trade models.[2]

Result 2. Both for leader and follower, relative wage is proportional to relative productivity. Technological convergence leads to factor price equalization.

Both countries allocate national income between domestic and imported goods. Because technological convergence raises the follower's output, and in each variety reduces its relative price, the leader's relative demand for the follower's products rises. Likewise, the decline in the follower's terms of trade reduces the imported share of its consumption ($TR / w^* L^*$).

Result 3. Technological convergence increases (decreases) the leader's (follower's) imported share of consumption.

Results 1 and 3 have received much attention in the convergence literature. Claims that the leader's comparative advantage or competitiveness erodes in the presence of convergence have been based on measures of global production and import share (Baumol, Nelson, and Wolff 1994; Keller 2001). However, the leader's welfare depends not on such shares, but on changes in its real income and terms of trade. In our setting, the leader's real income (w / p) is unchanged because we treat β as given. But the leader's terms of trade do improve. Hence, contrary to popular claims, the leader's welfare unambiguously improves when the follower catches up to the leader's technology (equation I.6, appendix I). At the same time, convergence is not necessarily a win-win outcome for the follower, because the follower's welfare depends on the relative strength of terms-of-trade and income effects.[3]

Result 4. Real-income and terms-of-trade are both welfare-improving. Technological convergence unambiguously benefits the leader by increasing its terms of trade. The follower's welfare change depends upon convergence's positive real-income impact relative to its negative terms-of-trade impact.

Results 1 through 4 are derived under the assumption that one monopolistically competitive sector, with an increasing-returns-to-scale technology, operates in each country. Labor is the only production factor. To examine the sensitivity of Results 1 – 4 to these assumptions, we also assessed convergence in the context of a traditional trade model, employing a specific-factors model as in Jones and Scheinkman (1977). Outcomes were similar to those in Results 1-4. See Appendix II for details.

2.3 Empirical Framework for Technological Convergence

In our empirical application, we represent technology by total factor productivity, estimated from an econometric specification of a value-added function (Bernard and Jones 1996a; Harrigan 1999; Miller and Upadhyay 2002).[4] Details of the assumed value-added structure, which permits variable returns-to-scale, are provided in Appendix III. The approach in Appendix III allows, consistent with the convergence literature (Miller and Upadhyay 2002; Bernard and Jones 1996a; Baumol, Nelson, and Wolff 1994; Ark and Pilat 1993), hypothesis tests about the robustness of cross-country TFP measures.[5]

The internationally comparable database described below permits cross-country comparisons of both TFP level and rate.

Industry- and country-specific time-series data on TFP levels permit us to measure each follower's TFP relative to that of the leader. To examine industry-specific β-convergence, the relationship between followers' relative TFP growth rates and followers' initial relative TFP levels is specified as:

(2.4) $$\Delta \ln(RTFP_{ci}) = \delta_0 + \delta_i D_i \ln(RTFP_{ci0}) + \varepsilon_{1ci},$$

where $\Delta \ln(RTFP_{ci})$ denotes, in industry *i* and over *T* periods, the average growth rate of country *c*'s productivity relative to the leader; $\ln(RTFP_{ci0})$ denotes country *c*'s relative TFP level in industry *i* during the base year; D_i is the industry-specific dummy variable; δ_i is the industry-specific slope parameter; and ε_{1ci} is a disturbance term. When $\delta_i < 0$, countries with lower relative TFP levels have faster relative TFP growth, which is evidence of followers' catch-up with the leader, i.e., productivity convergence (Bernard and Jones 1996a). Following Bernard and Jones (1996a), we derive the speed or rate of productivity convergence in industry *i*, λ_i, given the sample length *T*:

(2.5) $$\delta_i = -[1-(1-\lambda_i)^T]/T .$$

Positive λ_i implies followers are catching-up to leader's productivity level and the rate of convergence is inversely related to the magnitude of δ_i (Bernard and Jones 1996a). In equation (2.4), $\delta_i D_i \ln(TFP_{ci0})$ captures the proportion of followers' TFP growth rate attributable to technological “catch up”, while TFP growth induced by factors other than convergence is given by $\delta_0 + \varepsilon_{1ci}$.

2.4 Empirical Specification of Welfare Effects

To empirically examine our Results 1-4 regarding convergence effects, we first estimate the welfare impacts of followers’ relative TFP growth, then, based on equation (2.4), decompose welfare changes into those attributable to convergence as opposed to nonconvergence factors.

Result 1 shows that convergence raises the follower’s and reduces the leader’s global production share. We therefore use a first-order linear approximation of equation (I.1) in Appendix I to estimate convergence effects on followers’ share in global production:

(2.6) $$\Delta S_{ci} = \varphi_{0c} + \varphi_1 \Delta \ln(RTFP_{ci}) + \varphi_2 \Delta Ks_{ci} + \varphi_3 \Delta Ls_{ci} + \varepsilon_{2ci},$$

where ΔS_{ci} denotes, in industry i and over T periods, the average growth rate of follower-country c’s share in global value-added, and ε_{2ci} is the disturbance term. To control for unobserved heterogeneity across countries, we introduce a country fixed effect, φ_{0c}. Given equation (I.1), we expect a positive sign on φ_1. Equation (2.4)’s decomposition of follower’s relative TFP growth would then identify the impact of technological convergence on the growth rate of follower’s share of global value-added. All else constant, any gain to follower’s production share due to convergence is also a measure of the erosion of leader’s competitiveness. Control variables in equation (2.6) are ΔKs_{ci} and ΔLs_{ci}, respectively denoting the average growth rate of country c’s global capital and labor share. Parameters φ_2 and φ_3 are expected to take a positive sign because relative factor accumulation increases a country's value-added.

According to Result 2, convergence reduces the wage gap between the leader and followers. Similar to equation (2.6), a first-order linear approximation of equation (I.2) is:

$$\Delta Wage_{ci} = \gamma_{0c} + \gamma_1 \Delta \ln(RTFP_{ci}) + \gamma_2 \Delta Cap_{ci} + \varepsilon_{3ci}, \tag{2.7}$$

where $\Delta Wage_{ci}$ denotes, in industry *i*, the average growth rate of country *c*'s relative wage over *T* periods and ε_{3ci} is the disturbance term. As before, γ_{0c} represents country-specific intercepts. We expect γ_1 to be positive because higher relative TFP growth increases followers' relative wages. The control variable in the relative wage equation (2.7), is ΔCap_{ci}, which denotes the average growth rate of country *c*'s capital-labor ratio in industry *i*. The coefficient γ_2 is expected to capture the positive impact of the growth of the capital-labor ratio on the marginal product of labor and wages. The impact of technological convergence again can be derived from the decomposition of relative TFP growth in equation (2.4).

To identify convergence's effects on a follower's imported share of consumption (Result 3), we specify:

$$\Delta Ims_{ci} = \omega_{0c} + \omega_1 \Delta \ln(RTFP_{ci}) + \omega_2 \Delta Kr_{ci} + \omega_3 \Delta Lr_{ci} + \varepsilon_{4ci}, \tag{2.8}$$

where ΔIms_{ci} denotes, in industry *i* and over *T* periods, the average growth rate of country *c*'s imported share of consumption. Imports only from the leader are considered in equation (2.8). A follower's total consumption equals its domestic output plus imports from the leader less exports to the leader. Result 3 and equation (I.4) suggest ω_1 should be negative. The intercepts, ω_{0c}, account for country-specific effects. Control variables ΔKr_{ci} and ΔLr_{ci} respectively denote follower-country *c*'s average capital and labor growth relative to those of the leader. Both should reduce the follower's imported share of consumption since an increase in the follower's relative factor accumulation improves its relative supply of each of the consumption goods in world markets.

Our final empirical specification deals with leaders' and followers' welfares. The leader's welfare is represented by its total consumption, which equals the leader's output plus its imports from follower *c* less its exports to country *c*. Equation (I.6) shows that technological convergence improves the leader's national welfare by improving its terms of trade. The leader's welfare also is enhanced by its own TFP growth and factor accumulation. Controlling for country-specific fixed effects, the leaders' welfare is specified as:

$$\Delta Lwelfare_{ci} = \eta_{0c} + \eta_1 \Delta \ln(LTFP_i) + \eta_2 \Delta \ln(RTFP_{ci}) + \eta_3 \Delta Lk_i + \eta_4 \Delta Ll_i + \varepsilon_{5ci}, \tag{2.9}$$

where $\Delta Lwelfare_{ci}$ denotes, in industry *i* over *T* periods, the average growth rate of the leader's welfare; $\Delta \ln(LTFP_i)$ is the leader's average TFP growth in industry i; and control variables ΔLk_i and ΔLl_i are respectively the leader's average capital and labor growth in the i^{th} industry. As improvement in the leader's terms of trade comes solely from technical convergence, the follower's comparative average productivity growth, $\Delta \ln(RTFP_{ci})$, represents the terms-of-trade effect. All variables in (2.9) should have a positive coefficient.

Recall from Result 4 (equation I.7) that convergence has two opposite influences on followers' welfare: a positive real-income effect and a negative terms-of-trade effect. As shown in equation (I.7), real income is determined only by technology growth, so that convergence's real-income effect is reflected empirically by the follower's TFP growth rate. The terms-of-trade effect, however, is captured by the follower's relative TFP growth. Thus, we can estimate convergence's effect on followers' welfare with country-specific intercepts as:

(2.10) $$\Delta Fwelfare_{ci} = \phi_{0c} + \phi_1 \Delta\ln(TFP_{ci}) + \phi_2 \Delta\ln(RTFP_{ci}) + \phi_3 \Delta K_{ci} + \phi_4 \Delta L_{ci} + \varepsilon_{6ci}\,.$$

$\Delta Fwelfare_{ci}$ is follower c's average welfare growth rate – where welfare is the follower's domestic output plus imports from the leader less exports to the leader; $\Delta\ln(TFP_{ci})$ is average growth rate of country c's TFP; and ΔK_{ci} and ΔL_{ci} are country c's average capital and labor growth rates. Coefficients of all variables except $\Delta\ln(RTFP_{ci})$ in (2.10) should be positive. Following (2.4), we can decompose the real-income effect in equation (2.10) into those attributable to convergence and non-convergence factors.[6] A similar decomposition can also be made for the terms-of-trade effect in equation (2.9) and (2.10).

2.5 Data and Econometric Procedure

The United Nations Industrial Development Organization's (UNIDO) Industrial Statistical Database (INDSTAT4 2005) provides cross-country data on manufacturing industry value-added, employment, gross fixed capital formation, wages, and output. Data on 17 processed food industries, based on ISIC (Revision 3) 4-digit classifications in 30 countries from 1993 to 2001, are taken from INDSTAT4. Among the 30 countries, 10 are developed (Austria, Denmark, Finland, Italy, Japan, Norway, Portugal, Spain, United Kingdom, United States), and 20 are developing economies (Columbia, Cyprus, Ecuador, Eritrea, Ethiopia, India, Indonesia, Iran, Jordan, Korea, Malawi, Malaysia, Malta, Mexico, Mongolia, Oman, Panama, Singapore, Thailand, Turkey).

Data for some countries are available only in selected years, so data classified at ISIC Revision 2 are used to complete the series. In U.S. industries, correspondences between ISIC Revision 2 and Revision 3 are taken from U.S. Bureau of Census; we assume this correspondence is applicable to every nation.[7] As data availability varies by country and industry, we have an unbalanced data panel. Except for employment, which is expressed in labor units, production data are measured in INDSTAT4 in current local currencies. To render them internationally comparable, we first convert cross-country and -industry data to constant 2000 local currencies by using the corresponding price index from the World Bank's 2005 World Development Indicators (WDI). We then convert them to constant 2000 U.S. dollars by using the purchasing power parity (PPP) conversion factors from 2005 WDI.[8]

With data on annual gross fixed capital formation, we construct capital stock as a function of past investment flows, following the standard perpetual inventory equation with declining-balance depreciation (Crego *et al.* 1998; Hall *et al.* 1988):

(2.11) $$K_t = (1-d)K_{t-1} + I_t,$$

where I_t is gross fixed capital formation in year *t*, K_t is capital stock at end of year *t*, and d is depreciation rate.[9]

Bilateral trade data, expressed in nominal U.S. dollars, come originally from the COMTRADE database (United Nations) and are reclassified into ISIC (Revision 3) 4-digit-level industries. We adopt country-specific import and export price indexes from WDI and convert them to constant 2000 U.S. dollars.[10]

Our use of cross-country and -industry data suggests groupwise heteroskedasticity may impair efficient estimation of welfare equations (2.6) – (2.10). We therefore estimate three specifications of each welfare equation: ordinary least squares (OLS), feasible generalized least squares (FGLS) with cross-country heteroskedasticity, and FGLS with cross-industry heteroskedasticity. Likelihood ratio tests are employed to check for groupwise heteroskedasticity across country and industry.

2.6 Cross-Country/Industry Productivity Estimates and Convergence

Estimates of the determinants of country-level TFP, equation (III.3) in appendix III, are presented in table 2.1. Log of capital per unit labor is significant at the 1% level and indicates the elasticity of value added with respect to capital is 0.226. The statistically significant coefficient of the log of employment (-0.045) suggests food industries exhibit (marginally) decreasing returns to scale. Earlier studies have found mixed evidence of scale economies in processed food industries. For instance, focusing on aggregate processed-food industry data, Chan-Kang, Buccola, and Kerkvliet (1999) find modest scale economies in the U.S. food processing industry, while Gopinath (2003) finds significant scale diseconomies in 13 OECD countries. The elasticity of value-added with respect to employment, implicit in the coefficients of employment and capital per unit labor in table 2.1, is 0.729 (equation III.3). Processed food industries appear to be labor intensive, consistent with earlier analysis (Melton and Huffman 1995; Gopinath 2003).

Cross-country and -industry TFP estimates are derived for each year with the estimates in table 2.1, using equation III.4 in appendix III. An F-test rejects, at the 1% level, the null hypothesis of identical technologies across countries [F(29, 2972), 148.55]. Thus, TFP estimates show significant variation in level and growth rate across countries, among which the U.S. is the technological leader in 11 of 17 processed food industries (see table 2.2, drawn).[11] Previous studies have found U.S. TFP levels in most processed foods to be high as well (Harrigan 1997; Chan-Kang, Buccola, and Kerkvliet 1999; Gopinath 2003). Other leaders include Japan, Korea, Mexico, and Spain. Because our results are based on four-digit industries, the United States may not necessarily be the productivity leader in certain subsectors (e.g., sugar). Table 2.2 shows that the leader's average TFP growth rate has been generally higher than that of followers.[12]

Table 2.3 gives results of the β-convergence tests specified in equation (2.4), where a negative coefficient on the log of initial (relative) TFP suggests productivity convergence.[13] In 13 food industries – ISIC 1511-13, 1520, 1531, 1533, 1541, 1543, 1549, 1551-54 – the coefficient on the log of initial (relative) TFP is negative and significant at least at the 10% level. That is, countries with lower relative TFP levels have higher relative TFP growth, evidence of their catch-up with the leader, that is of productivity convergence. The convergence regression explains about 22.5% of the variation in the dependent variable; the rest likely is explained by R&D and technological opportunity and appropriability conditions (Cohen and Levin 1989).

Given the estimates of equation (2.4), we now identify the contribution of technological convergence to aggregate follower relative TFP growth. On average, followers' relative TFP grew 4.03% per year during the 1993-2001 period on account of their technological catch-up with the leader. During the same period, factors other than catch-up reduced their relative TFP growth by an annual 5.81%. The net effect is that followers' relative TFP fell 1.78% between 1993 and 2001 (table 2.2; see also table 2.5). A follower's relative TFP changes on account of events either in the leader or follower nation, indicated respectively in the denominator and numerator of equation (2.4)'s dependent variable. Research intensity and investment in technical development generally are higher in developed (leader) economies than in developing (follower) ones (Helpman 1997). Such factors shift the leader's technological frontier relative to the follower's, with effects that can linger for decades. Nevertheless, followers' relative TFP growth would have declined by 5.81% in the absence of technological convergence.

Equation (2.5) enables us to derive the mean rate of technological convergence in each of the 17 industries even though coefficient δ_i in equation (2.4) is not significant in four industries. Convergence rates, given in table 2.3, vary from 2.5% (ISIC 1531) to 9.5% (ISIC 1543) per year, pointing to the public-good nature of technology (Grossman and Helpman 1990). Our convergence rates are higher than those reported by Bernard and Jones (1996a) for OECD countries. In the latter study, the annual speed of TFP convergence is 6.50% in agriculture and 1.68% in manufacturing.

What explains the differences between the Bernard-Jones results and our own? First, productivity convergence rates likely have risen in recent years, as information technology and economic integration have accelerated. Second, productivity convergence probably has been slower among OECD countries, which already are comparatively developed, than elsewhere. Our findings certainly are consistent with Bernard and Jones' (1996a) expectation that nations adopting existing technology likely catch up much more quickly than do those inventing their own. Third, observed productivity in food sub-industries tends to catch up more rapidly than in the industry as a whole, since global trade – and associated cross-border technological transfers – increasingly have occurred between firms within a given ISIC four-digit industry aggregate.

2.7 Empirical Test of Convergence Effects

We turn now to testing our hypotheses about TFP convergence effects (Results 1 - 4). Tables 2.4a - 2.4d provide estimates of the effects of followers' relative TFP growth on their shares of global value-added, imported shares of consumption, relative wage, and welfare. Estimates of the leader's welfare equation are given in table 2.4e. For each Result 1 - 4 above, we present three sets of estimates, one corresponding to OLS, the second to FGLS with groupwise heteroskedasticity in the industry dimension, and the third to FGLS with groupwise heteroskedasticity in the country dimension. Heteroskedasticity in the country dimension is more evident than that in the industry dimension, so the following discussion focuses on the FGLS results accounting for the former. Moreover, our estimation includes country-specific fixed effects. Replacing country-specific effects with industry fixed effects does not alter the results in tables 2.4a-2.4e.

Beginning with table 2.4a, note that a follower's relative TFP growth, and to a lesser extent the growth rates in its shares of global capital and labor, significantly enhance its share of global value-added. Boosting the follower's relative TFP growth 1% raises the growth in its share of global value-added by 0.915%. Similarly, a 1% growth in the follower's capital-share and labor-share growth respectively lift its growth in global value-added share by 0.239% and 0.771%. Relative TFP growth's comparatively large impact on value-added share growth suggests total factor productivity is especially important for the follower's share in global production. The sign and significance of the estimated parameters are robust across the three estimators.[14]

Using equation (2.4), we next identify productivity convergence's effect on the growth of the follower's share of global value-added. Table 2.5 shows convergence increased followers' share of value-added by an average 3.69% per year during the 1993 – 2001 period. In the absence of convergence, followers' shares would have fallen by as much as 5.32% per year. All else constant, followers' gain in global value-added share implies a corresponding loss in leaders' share. However, factors other than convergence have increased the leaders' share in global value-added.

Table 2.4b reports, on the basis of equation (2.7), productivity convergence's effects on followers' relative wages. Both right-hand-side coefficient estimates have the expected positive sign and, in all three specifications, are statistically significant at the 1% level. R^2 in the OLS fit is 53.9%. If a follower's relative TFP rises 1%, its relative wage goes up 0.224%. Elasticity of the follower's relative wage with respect to its capital-labor ratio is 0.112, underscoring capital's impact on the marginal product of labor. Table 2.5 gives productivity convergence's contribution to the growth in followers' relative wages (0.90% per year). The mean wage gap between follower and leader would have widened by -1.30% per year in the absence of productivity convergence.

Effects of productivity convergence on followers' imported share of consumption are presented in table 2.4c. Consistent with Result 3, a 1% increase in the follower's relative TFP growth leads to a 0.819% fall in the growth rate of its imported consumption share. The follower's relative capital has no significant effect, but growth in its relative labor significantly reduces growth in its imported consumption share, with an elasticity of -0.455.[15] The latter result is consistent with our earlier finding that processed food industries are labor-intensive. Table 2.5 shows a follower's productivity convergence would decrease its imported share of consumption by an annual 3.30%, although owing to factors other than convergence, the growth in its imported share of consumption would rise 1.46% per year.

Table 2.4d provides estimates of equation (2.10), the effect of productivity convergence on followers' welfare. A 1% rise in a follower's TFP growth improves its welfare by 0.652%, suggesting that technological convergence has a strong, positive, real-income effect on its welfare. Capital and labor growth make their own positive contributions to welfare, with elasticities of 0.193% and 0.645% respectively. But as a proxy for terms-of trade, a follower's relative TFP does not reduce the follower's welfare significantly. Absolute TFP growth has in all three specifications a significant welfare-enhancing effect. Table 2.5 suggests technological convergence's positive real-income effect (2.63%) dominates the follower's welfare improvement, so followers realize net gains from convergence.

Table 2.4e shows, following equation (2.9), technological convergence's effects on leaders' welfare. The leader's absolute TFP growth significantly boosts its welfare growth rate (elasticity 0.342). Factor accumulation has similar effects: a one-percent rise in capital and labor growth lifts welfare growth by a respective 0.330% and 0.524%. Unlike in the follower's welfare equation, we find statistical evidence of terms-of-trade effects, i.e. the follower's relative TFP growth significantly enhances the leader's welfare in the country-groupwise FGLS estimates. Expressed differently, a 1% increase in a follower's relative TFP growth improves the leader's welfare by 0.016%, a finding consistent with the terms-of-trade effect in our Result 4.

2.8 Summary and Conclusions

We have investigated the welfare effects of technological convergence in the processed food industries by extending Krugman's monopolistic competition model. Convergence is reflected in a narrowing inter-country gap in fixed or marginal costs. Comparative statics indicates convergence between technological leader and follower enhances the follower's competitiveness – as reflected in its share of global production – but weakens the leader's. By improving the leader's terms of trade, convergence also improves leader welfare. The follower's welfare change depends upon convergence's positive income effect relative to its negative terms-of-trade effect.

Data from 17 processed food industries in 30 developed and developing nations were assembled to estimate, through a value-added equation, cross-country and cross-industry productivity level and growth. Estimates indicate significant cross-country variation in productivity level and growth rate. Technological convergence was then identified in each food industry through a regression of relative TFP growth rate on initial relative TFP level. Evidence of convergence is found in 13 of the 17 industries, and at rates generally higher than in earlier studies. Differences between our and earlier results likely can be attributed to aggregation and timing: our study focuses on the information-technology era in a setting with intra-industry trade.

We decomposed TFP growth into that arising from technological convergence and non-convergence factors. We then estimated convergence's effects on followers' global value-added share, relative wage, imported share of consumption, and follower and leader welfare. Estimates of technological convergence effects are robust across three alternative welfare-equation specifications.

Consistent with our analytical results, convergence increases followers' global production shares and relative wages. The implication is that follower competitiveness and relative wage would be substantially lower in the absence of technological convergence. On account of its positive income effect, technological convergence improves follower welfare. Convergence enhances leader welfare by boosting the leader's terms of trade. But any such terms-of-trade-induced gains would be less important to the leader than would its own technological progress.

Since the 1990s, deepening world trade liberalization has greatly facilitated technology transfers between high- and low-income economies, speeding followers' technological "catch-up". The present study shows convergence can improve both leader and follower welfare. That appears to recommend such liberalization policies as trade-barrier reductions and open foreign-investment regimes, which would bring long-run benefits to both leaders and followers. Yet economic factors that covary with technological convergence, for example public infrastructure and human capital, may also influence leader and follower welfare by way of income and terms-of-trade effects. Linkages between technology, trade, and economic growth likely are conditional on the quantity and quality of public-good investments. Future analysis employing longer productivity time series may improve our understanding of the relationships between technological convergence, public goods, and trade liberalization.

2.9 Endnotes

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[1] Relaxing the assumption of constant fixed cost complicates the analysis but does not affect our basic results.

[2] Note that complete factor price equalization requires convergence in both fixed cost and marginal cost. Here, marginal cost convergence reduces the technological and wage gap.

[3] If both fixed and marginal costs converge, the follower's global production share and relative wage will rise, while its imported share of consumption will fall. Terms of trade remain unchanged in both countries. However, both countries benefit from the increased number of goods.

[4] The terms "technological" and "productivity" convergence are used here synonymously.

[5] Recall in our theoretical model that a country's technological level is measured by its labor productivity (x/l or x^* / l^*). However, technological level is measured empirically here by total factor productivity (based on inputs of both capital and labor) rather than by labor productivity. The latter does not allow one to identify the separate influences of technology and capital growth (Bernard and Jones 1996b).

[6] Estimates of equation (2.4) can be used to decompose not only the follower's relative but absolute TFP growth.

[7] Some countries' data are in certain years available in both revisions. These data enable us to test the average difference between the data reported in Revision 3 and those converted, from the U.S. industry correspondences, from Revision 2 to Revision 3. Results of *t*-tests indicate that none of the data differences in value-added, employment, or gross fixed capital formation is significantly different from zero at the 5% significance level. Hence, we apply to other countries the U.S. correspondences between the two revisions.

[8] Manufacturing value-added price index and output price index are computed as the ratio of current to constant manufacturing value added; gross-fixed-capital-formation price index is computed as the ratio of current to constant gross fixed capital formation in the aggregate economy; and the consumer price index (CPI) of the aggregate economy is used to deflate wages.

[9] We follow Hall *et al.*'s (1988) procedure to obtain base-year capital stock data, given that I_{t_0} is base-year investment, initial capital stock K_{t_0} equals $\frac{I_{t_0}}{d+g}$, where g is pre-

sample annual growth rate of new capital. Country-specific pre-sample capital growth rates are derived as the average annual growth rates of gross fixed capital formation in the aggregate economy during the 10-year pre-sample period (WDI 2005). We set the depreciation rate (d) at 8% per year.

[10] The import (export) price index is calculated as the ratio of current to constant imports (exports) of goods and services in the aggregate economy.

[11] Except for ISIC 1542, U.S. production time-series data are unavailable in the five industries (ISIC 1532, 1541, 1543-44, 1549) for which the U.S. is not the technological leader.

[12] In most industries and countries, TFP grew during the 1993- 2001 interval. Exceptions include ISIC 1553, followers in ISIC 1514 and 1544, and leader in 1551. The relatively large decline in followers' TFP in ISIC 1544 can be explained by a sudden drop in Austrian output in 2000.

[13] We tested whether the intercepts in equation (2.4) are industry-specific. At the 5% significance level, an *F*-test cannot reject the null hypothesis that intercepts are identical across industries.

[14] Although R^2 is difficult to interpret in FGLS settings, our OLS fit of equation (2.6) explains 94.8% of the variation in growth rates of followers' global value-added shares.

[15] About 21.8% of the variation in followers' imported consumption shares is explained by the OLS regression of equation (2.8), since other factors, such as tariffs and other trade barriers, may also explain imported consumption share.

Table 2.1. Estimates of the Value-Added Equation (Dependent Variable: Log of Value-Added Per Worker, 1993-2001)

Independent variable	Estimates	
Log of capital per labor	0.226***	(18.99)
Log of employment	-0.045***	(-4.46)

Country-Specific Intercepts:			**Industry-Specific Intercepts:**			**Time-Specific Intercepts:**		
Austria	8.910***	(44.61)	1511	-0.478***	(-9.42)	1993	-0.076	(-1.53)
Colombia	9.622***	(50.23)	1512	-0.540***	(-9.99)	1994	-0.072	(-1.49)
Cyprus	8.712***	(48.85)	1513	-0.608***	(-11.71)	1995	-0.072	(-1.49)
Denmark	8.968***	(46.26)	1514	-0.110**	(-2.16)	1996	-0.052	(-1.08)
Ecuador	7.281***	(39.29)	1520	-0.220***	(-4.40)	1997	-0.022	(-0.46)
Eritrea	8.236***	(50.77)	1531	-0.204***	(-3.99)	1998	-0.046	(-0.97)
Ethiopia	8.458***	(48.49)	1532	-0.104	(-1.49)	1999	-0.013	(-0.27)
Finland	8.930***	(46.65)	1533	-0.160***	(-3.10)	2000	-0.036	(-0.77)
India	8.224***	(41.73)	1541	-0.515***	(-9.18)	2001	--	
Indonesia	7.973***	(40.57)	1542	-0.139**	(-2.42)			
Iran	8.598***	(44.57)	1543	-0.294***	(-5.27)			
Italy	9.107***	(43.16)	1544	-0.437***	(-7.35)			
Japan	9.527***	(46.16)	1549	-0.294**	(-5.29)			
Jordan	8.487***	(49.00)	1551	0.330***	(5.66)			
Korea	9.515***	(47.03)	1552	-0.193***	(-2.95)			
Malawi	7.031***	(36.39)	1553	0.532***	(9.68)			
Malaysia	8.727***	(44.95)	1554	--				
Malta	8.798***	(50.67)						
Mexico	9.149***	(45.69)						
Mongolia	6.690***	(35.19)						
Norway	8.959***	(46.48)						
Oman	8.232***	(41.58)						
Panama	8.335***	(45.44)						
Portugal	8.493***	(43.60)						
Singapore	8.688***	(47.06)						
Spain	9.218***	(46.12)						
Thailand	8.459***	(40.88)						
Turkey	9.259***	(48.35)						
United Kingdom	9.271***	(45.09)						
USA	10.045***	(48.06)						

R^2	0.998		
N= 3028			
F test: H_0: $b_{0c} = b_0 \quad \forall c$		$F\ (29,2972)$=148.55***	Reject H_0

*** indicates significance at 1%; ** indicates significance at 5%.
Numbers in parentheses are t-statistic of the coefficients.
Dummy variables of ISIC 1554 and year 2001 are dropped to avoid perfect multicollinearity.

Table 2.2. Productivity Leaders in 17 Processed Food Industries

Industry and ISIC code	Productivity leader	Average TFP growth rate over 1993-2001 (%)	
		The Leader	Followers
1511 Processing/preserving of meat	United States	4.80	2.19
1512 Processing/preserving of fish	United States	3.36	0.48
1513 Processing/preserving of fruits and vegetables	United States	4.23	1.51
1514 Vegetable and animal oils and fats	United States	2.64	-0.23
1520 Dairy products	United States	2.40	2.23
1531 Grain mill products	United States	1.15	-0.45
1532 Starches and starch products	Spain	4.39	1.35
1533 Prepared animal feeds	United States	2.34	0.83
1541 Bakery products	Japan	1.96	1.07
1542 Sugar	Korea	6.70	0.02
1543 Cocoa, chocolate and sugar confectionery	Japan	2.73	1.07
1544 Macaroni, noodle and similar products	Korea	4.42	-2.16
1549 Other food products n.e.c.	Mexico	2.29	2.21
1551 Distilling, rectifying and blending of spirits	United States	-0.04	0.47
1552 Wines	United States	2.76	3.32
1553 Malt liquors and malt	United States	-0.10	-0.37
1554 Soft drinks; mineral waters	United States	3.20	1.62

Table 2.3. Test of Productivity Convergence
Dependent Variable: Average Growth Rate of Followers' Relative TFP (1993-2001)

Independent variable	Estimates	Rate of Convergence
Intercept	-0.058*** (-8.46)	
Log of productivity level in 1993:		
1511 Processing/preserving of meat	-0.046*** (-4.54)	0.058
1512 Processing/preserving of fish	-0.032** (-2.19)	0.038
1513 Processing/preserving of fruits and vegetables	-0.024** (-2.26)	0.026
1514 Vegetable and animal oils and fats	-0.016 (-1.58)	0.018
1520 Dairy products	-0.049*** (-4.95)	0.062
1531 Grain mill products	-0.023*** (-3.07)	0.025
1532 Starches and starch products	-0.082 (-1.42)	0.137
1533 Prepared animal feeds	-0.045*** (-4.24)	0.057
1541 Bakery products	-0.055*** (-3.37)	0.073
1542 Sugar	-0.001 (-0.09)	0.001
1543 Cocoa, chocolate and sugar confectionery	-0.066* (-1.76)	0.095
1544 Macaroni, noodle and similar products	-0.026 (-0.74)	0.029
1549 Other food products n.e.c.	-0.046*** (-2.97)	0.058
1551 Distilling, rectifying and blending of spirits	-0.038*** (-3.78)	0.046
1552 Wines	-0.044*** (-3.97)	0.054
1553 Malt liquors and malt	-0.048*** (-3.81)	0.061
1554 Soft drinks; mineral waters	-0.039*** (-3.84)	0.047
R^2	0.225	
N= 302		

*** indicates significance at 1%; ** indicates significance at 5%; * indicates significance at 10%. Numbers in parentheses are t-statistic of the coefficients.

Table 2.4. Effects of Technological Convergence

2.4a. Estimates of Followers' Global Value-Added Share Equation
Dependent Variable: Average Growth Rate of Followers' Global Value-Added Share (1993-2001)

Independent variable	OLS	FGLS (grouped by industry)	FGLS (grouped by country)
Average growth rate of relative TFP over 1993-2001	0.909*** (43.03)	0.974*** (80.47)	0.915*** (49.80)
Average growth rate of global capital share over 1993-2001	0.248*** (12.84)	0.236*** (25.83)	0.239*** (17.09)
Average growth rate of global labor share over 1993-2001	0.753*** (33.72)	0.759*** (59.53)	0.771*** (44.69)
Country fixed effects F test: H_0: $b_{0c} = b_0 \ \forall c$	F (29, 270) = 0.43	χ^2 (29) = 13.28	χ^2 (29) = 47.61**
R^2 N= 303	0.948		
LR Test. H_0: No groupwise heteroskedasticity		χ^2 (16) = 310.10***	χ^2 (29) = 119.96***

2.4b. Estimates of Followers' Relative Wage Equation
Dependent Variable: Average Growth Rate of Followers' Relative Wage (1993-2001)

Independent variable	OLS	FGLS (grouped by industry)	FGLS (grouped by country)
Average growth rate of relative TFP over 1993-2001	0.216*** (5.86)	0.207*** (7.26)	0.224*** (8.59)
Average growth rate of relative capital intensity over 1993-2001	0.104*** (3.30)	0.103*** (3.72)	0.112*** (5.01)
Country fixed effects F test: H_0: $b_{0c} = b_0 \ \forall c$	F (27, 246) = 6.58***	χ^2 (27) = 263.58***	χ^2 (27) = 545.32***
R^2	0.539		
N= 276			
LR Test. H_0: No groupwise heteroskedasticity		χ^2 (16) = 80.84***	χ^2 (27) = 201.87***

2.4c. Estimates of Followers' Imported-Share-of-Consumption Equation
Dependent Variable: Average Growth Rate of Followers' Imported Consumption Share (1993-2001)

Independent variable	OLS	FGLS (grouped by industry)	FGLS (grouped by country)
Average growth rate of relative TFP over 1993-2001	-0.718*** (-3.10)	-0.816*** (-4.11)	-0.819*** (-4.18)
Average growth rate of relative capital over 1993-2001	0.118 (0.47)	0.187 (0.87)	-0.033 (-0.16)
Average growth rate of relative labor over 1993-2001	-0.513* (-1.84)	-0.526*** (-2.36)	-0.455** (-2.01)
Country fixed effects F test: H_0: $b_{0c} = b_0 \ \forall c$	F (23, 163) = 1.32	χ^2 (23) = 64.26***	χ^2 (22) = 47.06***
R^2	0.218		
N= 190			
LR Test. H_0: No groupwise heteroskedasticity		χ^2 (16) = 35.45***	χ^2 (23) =198.98***

2.4d. Estimates of Followers' Welfare Equation
Dependent Variable: Average Growth Rate of Followers' Welfare (1993-2001)

Independent variable	OLS	FGLS (grouped by industry)	FGLS (grouped by country)
Average growth rate of followers' TFP over 1993-2001	0.491** (2.36)	0.476*** (4.28)	0.652*** (7.75)
Average growth rate of relative TFP over 1993-2001	0.038 (0.19)	0.009 (0.09)	-0.089 (-1.14)
Average growth rate of followers' capital over 1993-2001	0.057 (0.66)	0.203*** (4.30)	0.193*** (5.10)
Average growth rate of followers' labor over 1993-2001	0.705*** (7.65)	0.632*** (16.71)	0.645*** (17.91)
Country fixed effects F test: H_0: $b_{0c} = b_0 \ \forall c$	F (23, 162) = 0.85	χ^2(23) = 124.99***	χ^2(22) = 117.19***
R^2 N= 190	0.589		
LR Test. H_0: No groupwise heteroskedasticity		χ^2(16) =181.75***	χ^2(23) =421.04***

2.4e. Estimates of Leader's Welfare Equation
Dependent Variable: Average Growth Rate of the Leader's Welfare (1993-2001)

Independent variable	OLS	FGLS (grouped by industry)	FGLS (grouped by country)
Average growth rate of leader's TFP over 1993-2001	0.303*** (5.03)	0.506*** (8.01)	0.342*** (5.65)
Average growth rate of relative TFP over 1993-2001	0.013 (0.67)	0.012 (1.02)	0.016*** (2.95)
Average growth rate of leader's capital over 1993-2001	0.318*** (4.78)	0.301*** (7.82)	0.330*** (6.15)
Average growth rate of leader's labor over 1993-2001	0.553*** (7.12)	0.368*** (6.43)	0.524*** (7.32)
Country fixed effects F test: H_0: $b_{0c} = b_0\ \forall c$	$F(23, 163) = 0.72$	$\chi^2(23) = 29.14$	$\chi^2(22) = 107.76$***
R^2	0.819		
$N = 191$			
LR Test. H_0: No groupwise heteroskedasticity		$\chi^2(16) = 149.91$***	$\chi^2(23) = 103.76$***

In tables 2.4a – 2.4e, *** indicates significance at 1% level; ** indicates significance at 5% level; * indicates significance at 10% level.
Numbers in parentheses are t-statistics.

Table 2.5. Decomposition of Relative TFP Growth Rate and Identification of Technological Convergence Effects on Follower Welfare, 1993-2001

	Average growth rate of relative TFP over 1993-2001	Relative TFP growth rate induced by technological convergence	Relative TFP growth rate induced by non-convergence factors
Mean	-1.78%	4.03%	-5.81%
<u>Global-value-added-share effect</u>			
OLS	-1.62%	3.66%	-5.28%
FGLS (grouped by industry)	-1.73%	3.93%	-5.66%
FGLS (grouped by country)	-1.63%	3.69%	-5.32%
<u>Relative-wage effect</u>			
OLS	-0.38%	0.87%	-1.25%
FGLS (grouped by industry)	-0.37%	0.83%	-1.20%
FGLS (grouped by country)	-0.40%	0.90%	-1.30%
<u>Imported-share-of-consumption effect</u>		-2.89%	4.17%
OLS	1.28%	-3.29%	4.74%
FGLS (grouped by industry)	1.45%	-3.30%	4.76%
FGLS (grouped by country)	1.46%		
<u>Real-income effect</u>			
OLS	-0.87%	1.98%	-2.85%
FGLS (grouped by industry)	-0.85%	1.92%	-2.77%
FGLS (grouped by country)	-1.16%	2.63%	-3.79%

2.10 References

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CHAPTER 3

WELFARE EFFECTS OF TECHNOLOGICAL CONVERGENCE IN INTERNATIONAL MANUFACTURING INDUSTRIES

3.1 Introduction

A key source of comparative advantage is technology, whose cross-country variation in level and growth strongly influences specialization and trade patterns (Trefler 1993, 1995; Dollar and Wolff 1993; Bernard and Jones 1996a; Harrigan 1997, 1999). With recent advances in information technology, concerns have risen on the erosion of technological advantage of industrialized economies (Baumol, Nelson, and Wolff 1994; Dollar and Wolff 1993; Bernard and Jones 1996a, 1996b; Keller 2001). For instance, emerging Asian and South American economies have increased their share of both supply and demand in global markets. Emerging economies not only have led the world production of unskilled goods, e.g. apparel and footwear, but also are supplying a growing share of skill-intensive products, e.g. automobiles and electronics. In the case of automobiles, for example, Korea accounted for 4.1% of global exports in 2005, but only 0.7% in 1990 (International Trade Statistics, World Trade Organization). The nature and rate of technological convergence between high- and low-income economies, and its consequence for both leaders and followers have become the core of an emerging literature (Krugman 1990; Coe, Helpman, and Hoffmaister 1997; Keller 2001; Samuelson 2004; Bhagwati, Panagariya, and Srinivasan 2004).

Krugman's (1990) technology-gap model, one of the few analytical studies on convergence, explores the welfare consequences of technological catch-up in the presence of inter-industry trade. Here, the leader (follower) specializes in more (less) technology-intensive goods. Then, narrowing inter-country technology gap raises the follower's relative wage, and improves its real income. However, the leader's terms of trade is worsened since the less technology-intensive goods become more expensive in terms of the leader's wage. In a similar context, Samuelson (2004) argues that if a less-developed country improves technology in its export industries, all countries benefit from the rise in global output. Yet if the same improvement is in a good exported from an advanced country, the latter loses on account of falling terms of trade. In a response to Samuelson (2004), Bhagwati, Panagariya, and Srinivasan (2004) point out that gains from growing intra-industry trade could offset the advanced country's losses due to declining trade terms.

The objective of this study is to analyze technological convergence and its consequences in manufacturing industries, which engage in intra-industry trade. Indeed global trade is increasingly intra-industry in nature, where Krugman's (1980) monopolistic competition model has been the basis of extensive gravity-type modeling of trade structure and patterns (Anderson and van Wincoop 2003; Feenstra 2004). We extend Krugman's (1980) monopolistic competition setting to model technological convergence as the source of narrowing inter-country gap in fixed or marginal costs of production. Our comparative-static results suggest convergence raises the follower's relative wage and global production share, a result consistent with Krugman's (1990) and Samuelson's (2004) claim. However, technological convergence also improves the leader's terms-of-trade, unambiguously improving its welfare. The latter result is consistent with Bhagwati, Panagariya, and Srinivasan's (2004) argument that leaders can benefit from convergence in the presence of intra-industry trade. Unlike in previous studies, the follower's welfare depends on the relative strength of its technological improvement and terms-of-trade decline.

Our empirical analysis includes 1993-2001 data from 35 countries (11 high-income, 24 low-income) in 128 manufacturing industries, defined on the basis of ISIC (Revision 3) 4-digit classification. We employ a value-added function allowing for country-, industry-, and time-specific effects to estimate total factor productivity (TFP) levels and growth rates, assuming variable returns to scale (Harrigan 1999). This approach permits hypothesis tests about the robustness of cross-country TFP measures. Moreover, TFP measuring bias due to scale economies is reduced by the assumption of variable returns to scale.[1] Technological or productivity convergence is identified by regressing TFP growth rates on initial TFP levels (β convergence) in each manufacturing industry (Bernard and Jones 1996a). We then empirically estimate welfare impacts of productivity convergence, including effects on the follower's global value-added share, relative wage, imported share of consumption, and welfare of both leader and follower.

3.2 Conceptual Framework

Our economic setting considers two countries, *A* and *B*, each of which produces a series of differentiated goods under monopolistic competition (Krugman 1980). Labor is the only input in production, which involves fixed (α) and variable (β) costs. Technology is expressed in unit labor requirements: $l_i = \alpha + \beta x_i$, where x_i denotes the output of the i^{th} good. As in Krugman's (1980) framework, an asterisk denotes the corresponding variable in country *B*. For example, country *B*'s technology is given by $l_i^* = \alpha^* + \beta^* x_i^*$.

International trade is costless, and consumers in either country consume all varieties produced by both countries.

The representative consumer's utility takes a CES form over a number of goods: $U = \sum_{i=1}^{n+n^*} c_i^\theta$, $0 < \theta < 1$, denotes the elasticity of substitution, c_i is consumption of the i^{th} good, and *n* (n^*) is the number of goods in country *A* (*B*). The i^{th} good's demand is:

$$c_i = \frac{wp_i^{1/(\theta-1)}}{\sum_{i=1}^{n+n^*} p_i^{\theta/(\theta-1)}}, \tag{3.1}$$

where w and p_i denote country *A*'s wage rate and the price of the i^{th} good, respectively.

Consistent with monopolistic competition, each firm produces a unique good in equilibrium. Profit maximization implies all firms charge a price equal to a constant markup over marginal cost ($p_i = \frac{\beta}{\theta} w$). Consequently, all goods produced within a country have the same price. Free entry leads to zero profit, yielding the equilibrium output of each good:

$$x_i = \frac{\alpha}{(p_i / w - \beta)} = \frac{\alpha\theta}{\beta(1-\theta)}, \qquad i = 1, \ldots, n \tag{3.2}$$

$$x_i^* = \frac{\alpha^*}{(p_i^* / w^* - \beta^*)} = \frac{\alpha^*\theta}{\beta^*(1-\theta)}, \qquad i = n+1, \ldots, n+n^*.$$

Equation (3.2) indicates all goods produced in the same country have identical output. Full labor employment generates the equilibrium number of varieties in each country:

$$n = \frac{L(1-\theta)}{\alpha}, \qquad n^* = \frac{L^*(1-\theta)}{\alpha^*}. \tag{3.3}$$

Note that country size (L or L^*) positively affects, and fixed cost (α or α^*) negatively affects, the number of varieties (n or n^*). In each country imports equal exports, given by $TR = \frac{wLw^*L^*}{wL + w^*L^*}$, where *TR* denotes trade.

To model technological convergence, we assume country *A* has a technological advantage over country *B*, i.e., $\alpha < \alpha^*, \beta < \beta^*$. Convergence is defined as a narrowing inter-country gap in fixed or marginal production costs, captured by a decline in α^* / α or β^* / β. Alternatively, convergence can be thought of as a narrowing difference between countries *A* and *B* in labor productivity (x / l and x^* / l^*). Our focus below is on marginal cost convergence, holding fixed costs constant.[2] We will refer to country *A* and *B* as leader and follower, respectively. Suppose the leader's marginal cost β is given, while the follower's marginal cost β^* is endogenously determined. In particular, β^* approaches β according to $\beta^* = \beta /(1 - e^{-\lambda})$, where λ is rate of convergence in marginal costs. The faster the technological convergence, the lower is the follower's marginal cost, i.e., $\frac{\partial \beta^*}{\partial \lambda} < 0$. We now outline our key comparative-static results and testable hypotheses. Technical derivations and proofs are in Appendix I.

Our first result pertains to the leader's and follower's global production share. In the presence of technological convergence, the leader's output will remain unchanged because its fixed and marginal costs remain the same. Since labor endowments and fixed costs do not change, the number of varieties in each country remains constant. However, as shown in equation (3.2), the follower's output of each variety increases with the decline in its marginal cost. As a result, the follower's relative supply increases, inducing an expansion in global supply. This is consistent with Krugman (1990) and the arguments of Bhagwati, Panagariya, and Srinivasan (2004).

Result 1. Technological convergence will increase (decrease) the follower's (leader's) global production share.

As Samuelson (2004) noted, a follower's technical progress can lower the leader's relative wage and living standards. We first address the change in the leader's wage rate relative to the follower's. The constant mark-up in each country can be used to derive this relative wage, which depends, as in Krugman (1980), on relative price and relative marginal cost. In our model, however, relative price depends on relative global supply, which in turn depends upon the technological convergence rate. While a one percent increase in follower's relative (labor) productivity brings a one percent increase in relative global supply, the corresponding terms-of-trade changes by less than one percent (equation I.2, appendix I). Convergence therefore has a net positive (negative) effect on the follower's (leader's) relative wage, so that factor prices tend to equalize, a frequent result in traditional and new trade models.[3]

Result 2. Both for leader and follower, relative wage is proportional to relative productivity. Technological convergence leads to factor price equalization.

Both countries allocate national income between domestic and imported goods. Because technological convergence raises the follower's output, and in each variety reduces its relative price, the leader's relative demand for the follower's products rises. Likewise, the decline in the follower's terms of trade reduces the imported share of its consumption ($TR / w^* L^*$).

Result 3. Technological convergence increases (decreases) the leader's (follower's) imported share of consumption.

Results 1 and 3 have received much attention in the convergence literature. Claims that the leader's comparative advantage or competitiveness erodes in the presence of convergence have been based on measures of global production and import share (Baumol, Nelson, and Wolff 1994; Keller 2001). However, the leader's welfare depends not on such shares, but on changes in its real income and terms of trade. In our setting, the leader's real income (w / p) is unchanged because we treat β as given. But the leader's terms of trade do improve. Hence, contrary to popular claims, the leader's welfare unambiguously improves when the follower catches up to the leader's technology (equation I.6, appendix I). At the same time, convergence is not necessarily a win-win outcome for the follower, because the follower's welfare depends on the relative strength of terms-of-trade and income effects.[4]

Result 4. Real-income and terms-of-trade are both welfare-improving. Technological convergence unambiguously benefits the leader by increasing its terms of trade. The follower's welfare change depends upon convergence's positive real-income impact relative to its negative terms-of-trade impact.

Similar to Krugman (1990), we find that technological convergence raises the follower's relative wage and global production share. However, the two studies differ on convergence's effects on the leader's terms of trade. With only inter-industry trade, Krugman (1990) shows that an increase in the follower's relative wage raises the production cost of less technology-intensive industries in which the follower specializes, and consequently worsens the leader's terms of trade. Hence, the potential gains from intra-industry trade are not captured in Krugman's (1990) results - a limitation pointed out by Bhagwati, Panagariya, and Srinivasan (2004). We instead assume a monopolistic-competition framework and consider the case of intra-industry trade. Here, the follower's relative productivity rises by more than the increase in its relative wage, and therefore, convergence reduces the follower output's relative price. The latter results in favorable terms of trade to the leader.

3.3 Empirical Framework of Technological Convergence

We empirically represent technology by total factor productivity, which is estimated from an econometric specification of a value-added function (Bernard and Jones 1996a; Harrigan 1999; Miller and Upadhyay 2002).[5] Details of the assumed value-added structure, which permits variable returns-to-scale, are provided in Appendix III. The approach in Appendix III, consistent with the convergence literature, allows hypothesis tests about the robustness of cross-country TFP measures (Miller and Upadhyay 2002; Bernard and Jones 1996a; Baumol, Nelson, and Wolff 1994; Ark and Pilat 1993).[6] The internationally comparable database described below permits cross-country comparisons of both TFP level and rate.

Industry- and country-specific time-series data on TFP levels permit us to measure each follower's TFP relative to that of the leader. To examine industry-specific β-convergence in productivity, the relationship between followers' relative TFP growth rates and followers' initial relative TFP levels is specified as:

(3.4) $$\Delta \ln(RTFP_{ci}) = D_i + \delta_i D_i \ln(RTFP_{ci0}) + \varepsilon_{1ci},$$

where $\Delta \ln(RTFP_{ci})$ denotes, in industry *i* and over *T* periods, the average growth rate of country *c*'s productivity relative to the leader; $\ln(RTFP_{ci0})$ denotes country *c*'s relative TFP level in industry *i* during the base year; D_i is the industry-specific dummy variable; δ_i is the industry-specific slope parameter; and ε_{1ci} is a disturbance term. When $\delta_i < 0$, countries with lower relative TFP levels have faster relative TFP growth, which is evidence of followers' catch-up with the leader, i.e., productivity convergence (Bernard and Jones 1996a). Following Bernard and Jones (1996a), we derive the speed or rate of productivity convergence in industry *i*, λ_i, given the sample length *T*:

(3.5) $$\delta_i = -[1-(1-\lambda_i)^T]/T \text{ .}$$

Positive λ_i implies followers are catching-up to leader's productivity level and the rate of convergence is inversely related to the magnitude of δ_i (Bernard and Jones 1996a). In equation (3.4), $\delta_i D_i \ln(TFP_{ci0})$ captures the proportion of a follower's relative TFP growth rate attributable to technological "catch up", while the contribution of non-convergence factors, e.g. R&D investments, is given by $D_i + \varepsilon_{1ci}$.

3.4 Empirical Specification of Welfare Effects

To empirically examine our Results 1-4 regarding convergence effects, we first estimate the welfare impacts of followers' relative TFP growth, then, based on equation (3.4), decompose welfare changes into those attributable to convergence as opposed to non-convergence factors.

Result 1 shows that convergence raises the follower's and reduces the leader's global production share. We therefore use a first-order linear approximation of equation (I.1) in Appendix I to estimate convergence effects on followers' share in global production:

$$\Delta S_{ci} = \varphi_{0c} + \varphi_{0i} + \varphi_1 \Delta \ln(RTFP_{ci}) + \varphi_2 \Delta Ks_{ci} + \varphi_3 \Delta Ls_{ci} + \varepsilon_{2ci}, \tag{3.6}$$

where ΔS_{ci} denotes, in industry *i* and over *T* periods, the average growth rate of follower-country *c*'s share in global value-added, and ε_{2ci} is the disturbance term. Such differences as market structures and institutional environments may cause cross-country and –industry heterogeneity, which are controlled respectively by country- and industry-fixed effects, φ_{0c} and φ_{0i}. Given equation (I.1), we expect a positive sign on φ_1. Equation (3.4)'s decomposition of follower's relative TFP growth would then identify the impact of technological convergence on the growth rate of follower's share of global value-added. All else constant, any gain to follower's production share due to convergence is also a measure of the erosion of leader's competitiveness. Control variables in equation (3.6), ΔKs_{ci} and ΔLs_{ci}, respectively denote the average growth rate of country *c*'s global capital and labor share. Parameters φ_2 and φ_3 are expected to take a positive sign because relative factor accumulation increases a country's value-added.

According to Result 2, convergence reduces the wage gap between the leader and followers. Similar to equation (3.6), a first-order linear approximation of equation (I.2) is:

$$\Delta Wage_{ci} = \gamma_{0c} + \gamma_{0i} + \gamma_1 \Delta \ln(RTFP_{ci}) + \gamma_2 \Delta Cap_{ci} + \varepsilon_{3ci}\,, \tag{3.7}$$

where $\Delta Wage_{ci}$ denotes, in industry *i*, the average growth rate of country *c*'s relative wage over *T* periods and ε_{3ci} is the disturbance term. As before, γ_{0c} represents country-specific intercepts, and γ_{0i} represents industry-specific intercepts. We expect γ_1 to take a positive sign because higher relative TFP growth increases followers' relative wages. The control variable in equation (3.7) is ΔCap_{ci}, denoting the average growth rate of country *c*'s capital-labor ratio in industry *i*. The coefficient γ_2 is expected to capture the positive impact of the growth of the capital-labor ratio on the marginal product of labor and wages. The impact of technological convergence again can be derived from the decomposition of relative TFP growth in equation (3.4).

To identify convergence's effects on a follower's imported share of consumption (Result 3), we specify:

$$\Delta Ims_{ci} = \omega_{0c} + \omega_{0i} + \omega_1 \Delta \ln(RTFP_{ci}) + \omega_2 \Delta Kr_{ci} + \omega_3 \Delta Lr_{ci} + \varepsilon_{4ci}\,, \tag{3.8}$$

where ΔIms_{ci} denotes, in industry *i* and over *T* periods, the average growth rate of country *c*'s imported share of consumption. Imports only from the leader are considered in equation (3.8). A follower's total consumption equals its domestic output plus imports from the leader less exports to the leader. Result 3 and equation (I.4) suggest ω_1 should be negative. The intercepts, ω_{0c} and ω_{0i}, account for country- and industry-specific effects respectively. Control variables ΔKr_{ci} and ΔLr_{ci} respectively denote follower-country *c*'s average capital and labor growth relative to those of the leader. Both should reduce the follower's imported share of consumption since an increase in the follower's relative factor accumulation improves its relative supply of each of the consumption goods in world markets.

Our final empirical specification deals with leaders' and followers' welfares. The leader's welfare is represented by its total consumption, which equals the leader's output plus its imports from follower *c* less its exports to country *c*. Equation (I.6) shows that technological convergence improves the leader's national welfare by improving its terms of trade. The leader's welfare also is enhanced by its own TFP growth and factor accumulation. Therefore, the leaders' welfare is specified as:

(3.9) $$\Delta Lwelfare_{ci} = \eta_{0c} + \eta_{0i} + \eta_1 \Delta \ln(LTFP_i) + \eta_2 \Delta \ln(RTFP_{ci}) + \eta_3 \Delta Lk_i + \eta_4 \Delta Ll_i + \varepsilon_{5ci},$$

where $\Delta Lwelfare_{ci}$ denotes, in industry *i* over *T* periods, the average growth rate of the leader's welfare; $\Delta \ln(LTFP_i)$ is the leader's average TFP growth in industry i; and control variables ΔLk_i and ΔLl_i are respectively the leader's average capital and labor growth in the i^{th} industry. As improvement in the leader's terms of trade comes solely from technical convergence, the follower's comparative average productivity growth, $\Delta \ln(RTFP_{ci})$, represents the terms-of-trade effect. All the explanatory variables should have a positive coefficient. η_{0c} and η_{0i} respectively denote country- and industry-fixed effects in equation (3.9).[7]

Recall from Result 4 (equation I.7) that convergence has two opposite influences on followers' welfare: a positive real-income effect and a negative terms-of-trade effect. As shown in equation (I.7), real income is determined only by technology growth, so that convergence's real-income effect is reflected empirically by the follower's TFP growth rate. The terms-of-trade effect, however, is captured by the follower's relative TFP growth. Thus, we can estimate convergence's effect on followers' welfare with country- and industry- specific intercepts as:

(3.10) $$\Delta Fwelfare_{ci} = \phi_{0c} + \phi_{0i} + \phi_1 \Delta \ln(TFP_{ci}) + \phi_2 \Delta \ln(RTFP_{ci}) + \phi_3 \Delta K_{ci} + \phi_4 \Delta L_{ci} + \varepsilon_{6ci}\,.$$

$\Delta Fwelfare_{ci}$ is follower c's average welfare growth rate – where welfare is the follower's domestic output plus imports from the leader less exports to the leader; $\Delta \ln(TFP_{ci})$ is average growth rate of country c's TFP; and ΔK_{ci} and ΔL_{ci} are country c's average capital and labor growth rates. Coefficients of all variables except $\Delta \ln(RTFP_{ci})$ in (3.10) should be positive. Following (3.4), we can decompose the real-income effect in equation (3.10) into those attributable to convergence and non-convergence factors.[8] A similar decomposition can also be made for the terms-of-trade effect in equation (3.9) and (3.10).[9]

3.5 Data and Econometric Procedure

The United Nations Industrial Development Organization's (UNIDO) Industrial Statistical Database (INDSTAT4 2005) is the source of manufacturing industry data on value-added, employment, gross fixed capital formation, wage, and output. Our empirical analysis includes all 128 manufacturing industries classified at ISIC (Revision 3) 4-digit levels. For each industry, we have assembled data for 35 countries for 1997-2001. Among the 35 countries, 12 are developed (Australia, Austria, Denmark, France, Finland, Italy, Japan, Norway, Portugal, Spain, United Kingdom, United States), and 23 are developing economies (Columbia, Cyprus, Ecuador, Eritrea, Ethiopia, India, Indonesia, Iran, Jordan, Korea, Kuwait, Malawi, Malaysia, Malta, Mexico, Mongolia, Oman, Panama, Singapore, Sri Lanka, Thailand, Tunisia, Turkey). For 28 of 128 industries, the sample period is expanded to 1993-2001 since we have a one-to-one correspondence between ISIC Revision 2 and Revision 3 classifications. This correspondence allows us to use data classified at ISIC Revision 2 to extend the time series of these 28 industries to 1993-2001.[10] In the empirical analysis, we test each theoretical hypothesis using the 28-industry sample that cover the period of 1993-2001 (sample A), and the 100-industry sample with 1997-2001 data (sample B).

As data availability varies by country and industry, we have an unbalanced data panel. Except for employment, which is expressed in labor units, production data are measured in INDSTAT4 in current local currencies. To render them internationally comparable, we first convert cross-country and -industry data to constant 2000 local currencies by using the corresponding price index from the World Bank's 2005 World Development Indicators (WDI). We then convert the latter to constant 2000 U.S. dollars by using the purchasing power parity (PPP) conversion factors from 2005 WDI.[11]

With data on annual gross fixed capital formation, we construct capital stock as a function of past investment flows, following the standard perpetual inventory equation with declining-balance depreciation (Crego *et al.* 1998; Hall *et al.* 1988):

(3.11) $$K_t = (1-d)K_{t-1} + I_t,$$

where I_t is gross fixed capital formation in year *t*, K_t is capital stock at end of year *t*, and d is depreciation rate.[12]

Bilateral trade data, expressed in nominal U.S. dollars, come originally from the COMTRADE database (United Nations) and are reclassified into ISIC (Revision 3) 4-digit-level industries. We adopt country-specific import and export price indexes from WDI and convert them to constant 2000 U.S. dollars.[13]

Our use of cross-country and -industry data suggests groupwise heteroskedasticity may impair efficient estimation of welfare equations (3.6) – (3.10). We therefore estimate three specifications of each welfare equation: ordinary least squares (OLS), feasible generalized least squares (FGLS) with cross-country heteroskedasticity, and FGLS with cross-industry heteroskedasticity. Likelihood ratio tests are employed to check for groupwise heteroskedasticity across country and industry.

3.6 Cross-Country/Industry Productivity Estimates and Convergence Rates

Estimates of the value-added function, equation (III.3) in appendix III, are presented in table 3.1. Log of capital per unit labor is significant at the 1% level and indicates the elasticity of value added with respect to capital is 0.201. The statistically significant coefficient of the log of employment (0.048) suggests manufacturing industries exhibit increasing returns to scale in the aggregate. Earlier studies have found mixed evidence of scale economies for manufacturing industries. Antweiler and Trefler (2002), in their investigation of scale elasticities for 34 industries (including 27 manufacturing industries) in 71 countries, find increasing returns in seven manufacturing industries. Harrigan (1999) finds little evidence of scale economies in his production function estimates for 11 OECD countries. However, Morrison Paul and Siegel (1997) find significant scale economies in a number of U.S. manufacturing industries. The elasticity of value-added with respect to employment is 0.847 (equation III.3).

Cross-country and -industry TFP estimates are derived for each year with the estimates in table 3.1 using equation III.4 in appendix III. An F test rejects the null hypothesis of identical technologies across countries [F(34, 13406), 478.55] at the 1% level, which suggests significant cross-country variation in TFP levels and growth rates. Our TFP estimates in table 3.2 indicate that United States is the technological leader in 75 of 128 industries, which is consistent with previous studies (Harrigan 1997; Bernard and Jones 1996a).[14] In addition, the United States has the second highest TFP level in 26 of the remaining 53 industries. Other technology leaders include Australia, Austria, Finland, Italy, Korea, Japan, Mexico, Norway, France, Singapore, and Turkey. Table 3.2 shows that the leader's average TFP growth rate is generally higher than that of the followers. Moreover, the TFP growth rate in most countries and industries remained positive over 1993-2001, with few exceptions - ISIC 1512, 1514, 1533, 1551, 1553, 1730, 1911, 3330, and 3692. However, TFP growth rates are more variable across industries and countries during 1997-2001. The leader in several industries has experienced severe productivity decline (ISIC 1544, 2310, 2330, 2914, 2923, 3313, and 3720). The last two results may arise from the short sample period and the East Asian financial crisis of the late 1990s.

Table 3.3 provides results of the β-convergence tests specified in equation (3.4), where a negative coefficient on the log of initial (relative) TFP indicates productivity convergence. Of the 28 industries in sample A, 16 industries show a negative coefficient on the log of initial relative TFP with significance at least at the 10% level (ISIC 1511, 1513, 1520, 1531, 1533, 1551-54, 1600, 1722, 1723, 1730, 2511, 2691, and 2694), confirming evidence of followers' technological catch-up with the leader, i.e., productivity convergence. The convergence regression explains about 44.6% of the variation in followers' relative TFP growth; the rest likely is explained by R&D and technological opportunity and appropriability conditions (Cohen and Levin 1989). An F test rejects the null hypothesis of identical intercepts across industries at 1% significance level [F(27, 502), 2.15], indicating the effects of non-convergence factors on followers' relative TFP growth differ across industries.

For sample B, the coefficient on followers' initial relative TFP levels is significantly negative in only 18 of 100 industries (ISIC 1544, 1820, 2010, 2029, 2230, 2310, 2411, 2520, 2610, 2710, 2911, 2912, 2924, 3120, 3320, 3420, 3430, and 3610). Again, the convergence regression explains about 51.9% of the variation in the followers' relative TFP growth rate (table 3.3). Rejecting the null hypothesis of identical intercepts across industries, an F test [F(98, 1555), 7.68] suggests the existence of industry-specific effects on followers' relative TFP growth rates. As noted earlier, the infrequent convergence evidence in 1997-2001 may be related to the length of available time series.

Estimation of equation (3.4) enables us to identify the contribution of technological convergence to followers' relative TFP growth in aggregate manufacturing. On average, followers' relative TFP grew 4.02% per year during 1993-2001 on account of their technological catch-up with the leader. Factors other than catch-up reduced their relative TFP growth by an annual 7.57% during the same period. The net effect is that followers' relative TFP fell 3.54% between 1993 and 2001. Over 1997-2001, technological convergence raised followers' relative TFP by an average of 2.74%, but followers' relative TFP declined 4.10% per year due to non-convergence factors, and consequently the net change of followers' relative TFP was -1.36% per year during this period.

A follower's relative TFP changes on account of events either in the leader or follower nation, indicated respectively in the denominator and numerator of equation (3.4)'s dependent variable. Research intensity and investment in technical development generally are higher in developed (leader) economies than in developing (follower) ones (Helpman 1997). Such factors shift the leader's technological frontier relative to the follower's, with effects that can linger for decades. Kumar and Russell (2002) indicate that technological change is non-neutral, benefiting rich economies (leaders) more than the poor (followers). In our convergence regression, equation (3.4), most industries have a negative intercept, suggesting TFP growth induced by non-convergence factors, such as R&D investments, is lower in followers relative to leaders.

We derive the rate of technological convergence, equation (3.5), for industries with a significant and negative coefficient on the log of initial (relative) TFP in equation

(3.4) in the two samples. Convergence rates, given in table 3.3, vary from 4.09% (ISIC 1723) to 10.48% (ISIC 1511) per year during 1993-2001, and from 6.07% (ISIC 3420) to 11.97% (ISIC 2924) annually over 1997-2001, indicating the public-good nature of technology (Grossman and Helpman 1990; Coe, Helpman, and Hoffmaister 1997). Bernard and Jones (1996a) find a convergence rate of 1.68% per year in the aggregate manufacturing industry of 14 OECD countries during 1970-1987. Note that the present study examines convergence in four-digit manufacturing industries and includes high- and low-income economies. Our higher convergence rates relative to those reported by Bernard and Jones (1996a) are consistent with the latter's argument that nations adopting existing technology likely catch up much more quickly than do those inventing their own. Moreover, the variation in the rate of technological convergence in both sample periods suggest cross-industry differences in global trade volume and the degree of openness.[15]

3.7 Empirical Test of Convergence Effects

We next test our hypotheses on TFP convergence effects, Results 1 – 4 from the Conceptual Framework. Tables 3.4a – 3.4d provide estimates of the effects of followers' relative TFP growth on their share of global value-added, relative wage, imported share of consumption, and welfare. Estimates of the leader's welfare equation are given in table 3.4e. For each Result 1 – 4 above, we present three sets of estimates: OLS, FGLS with industry (groupwise) heteroskedasticity, and FGLS with country (groupwise) heteroskedasticity. The empirical results are quantitatively and qualitatively similar across the three estimators. However, the following discussion focuses on the FGLS estimates with country-groupwise heteroskedasticity, where we found evidence of two-way fixed effects, country and industry, in most cases.

Table 3.4a reports the effects of followers' relative TFP growth on their global value-added shares. During 1993-2001, a 1% growth in a follower's relative TFP significantly enhances its share in global value-added by 0.929% per year. Similarly, a 1% increase in the follower's global capital (labor) share raises its value-added by 0.200% (0.838%). In sample A, we did not find significant evidence of country-fixed effects, but faced perfect fit when 4-digit industry-fixed effects are included in equation (3.6), i.e., R^2 in OLS is 100%. Therefore, we include 3-digit industry-fixed effects in equation (3.6). For example, the four industries: ISIC 1511, 1512, 1513 and 1514 are aggregated into a single industry (ISIC 151) for the purpose of estimating industry-fixed effects only. In sample A, twenty eight 4-digit industries are aggregated into seventeen 3-digit industries, while the one hundred 4-digit industries in sample B yields 52 industries at the 3-digit level. Note that the other variables in equation (3.6) are held at the 4-digit level. The 3-digit industry fixed effects are significant at the 1% level in all three alternative estimates, suggesting cross-industry heterogeneity in the growth of followers' global value-added shares. The R^2 in the OLS regression is 97.8%, which indicates that equation (3.6) well fits observed data during 1993-2001.

During the 1997-2001 period, a 1% increase in a follower's relative TFP brings about a 0.670% rise in its global value-added share. Increase in the follower's global capital and labor share enhances its global value-added share as well, with elasticities of 0.140% and 0.876%, respectively. Both country- and 3-digit industry-specific effects are found to be significant in sample B, and the OLS R^2 is 89.6%. We find followers' relative TFP growth significantly improves their shares in global value-added in both time periods, consistent with our theoretical predictions. However, the magnitude of this latter effect is larger in the longer sample (1993-2001).

We use equation (3.4) to identify the technological convergence's effect on the growth of followers' share in global value-added. Table 3.5 shows that technological convergence increased followers' share of value-added by 3.73% per year during the period of 1993-2001, and by 1.84% per year during 1997-2001. In the absence of convergence, followers' shares would have fallen by as much as 7.03% per year over 1993-2001, and by an annual average of 2.75% over 1997-2001. All else constant, followers' gain in global value-added share implies a corresponding loss in leaders' share. However, factors other than technological convergence, e.g. R&D investments, may have increased leaders' share in global value-added.

Table 3.4b reports, on the basis of equation (3.7), productivity convergence's effects on followers' relative wages. Over 1993-2001, increases in both followers' relative TFP and their capital-labor ratio have the expected positive effects, which are statistically significant at the 1% level in all three specifications. If a follower's relative TFP rises 1%, its relative wage goes up 0.208%. Elasticity of the follower's relative wage with respect to its capital-labor ratio is 0.064, underscoring capital's impact on the marginal product of labor. During 1997-2001, the follower's relative TFP growth significantly raises its relative wage, with an elasticity of 0.144, but the coefficient on the capital-labor ratio is not significant. The significant effects of relative TFP growth in both sample periods indicate the key role of productivity in wage determination (Result 2). Productivity convergence raises followers' relative wages by an annual average of 0.84% and 0.39% respectively during the period of 1993-2001, and 1997-2001 (table 3.5). In these two periods, the mean wage gap between followers and leaders would have widened by -1.57% and -0.59% per year respectively in the absence of productivity convergence.

Effects of productivity convergence on followers' imported share of consumption are presented in table 3.4c. A 1% increase in a follower's relative TFP growth leads to a 0.917% fall in the average growth rate of its imported consumption share over 1993-2001, consistent with Result 3. Growth in followers' relative labor significantly reduces growth in its imported consumption share, with an elasticity of -0.963, but the effect of relative capital growth is not significant. The estimates for sample B, 1997-2001, are similar, but the effects are lower in absolute terms. For the two samples, A and B, OLS regression explains respectively 33.8% and 29.4% of variation in followers' imported share of consumption. It is likely that trade barriers and distance costs may explain the rest of the variation in imported consumption share. Table 3.5 shows that followers' productivity convergence would have decreased their imported share of consumption by an annual 3.69% in 1993-2001 and 1.51% in 1997-2001, but these effects are offset by non-convergence, which resulted in net growth in imported share of consumption by 3.25% and 0.75% per year respectively in the two samples.

Table 3.4d presents the effects of productivity convergence on followers' welfare [equation (3.10)]. Every 1% increase in a follower's TFP growth rate enhances its welfare growth rate by an average of 0.602% during 1993-2001, suggesting that technological convergence has a strong, positive, real-income effect on its welfare. Capital and labor growth also contribute to welfare improvement, with elasticity of 0.197% and 0.841% respectively. But as a proxy for terms-of trade, the follower's relative TFP growth does not significantly affect its welfare. Similar results, albeit with lower magnitude, are observed in sample B, 1997-2001. In both sample periods, the welfare-enhancing effect of the followers' absolute TFP growth is robust across three alternative estimates. As in table 3.4a, we introduce 3-digit industry dummies in equation (3.6) to avoid perfect multicollinearity. Industry- and country-fixed effects are significant in both sample periods, suggesting cross-country and –industry heterogeneity exists in followers' welfare growth. Table 3.5 shows technological convergence's positive real-income effect (2.24% for sample A and 1.41% for sample B), but followers' net welfare change is negative due to non-convergence factors.

Table 3.4e shows, following equation (3.9), technological convergence's effects on leaders' welfare. The leader's absolute TFP growth significantly boosts its welfare growth rate with an elasticity of 0.511 in the period of 1993-2001. Factor accumulation also enhances welfare: a one-percent rise in capital and labor growth lifts welfare growth by a respective 0.223% and 0.734%. We find little evidence of terms-of-trade improvement for leaders since our proxy, follower's relative TFP growth, does not significantly affect leader's welfare. Results for the sample period of 1997-2001 are similar. At the aggregate level, the empirical results suggest that a leader's own technological progress is the key to its welfare improvement, while terms-of-trade effects appear less important.[16] However, for some industries the latter effect may be significant.

3.8 Summary and Conclusions

This paper has investigated the welfare effects of technological convergence in international manufacturing industries by extending Krugman's monopolistic competition model. Comparative statics indicate convergence between a technological leader and a follower enhances the follower's competitiveness - as reflected in its share of global production - but weakens that of the leader. By improving the leader's terms of trade, convergence also improves leader welfare, a result different from earlier models. The follower's welfare change depends upon convergence's positive income effect relative to its negative terms-of-trade effect.

We estimated cross-country and –industry productivity levels and growth rates through a value-added function. Dataset in our study covers 35 developed and developing economies in 128 manufacturing industries at the ISIC (Revision 3) 4-digit classifications. Technological convergence was identified in each manufacturing industry through a regression of relative TFP growth rate on initial relative TFP level, and evidence of convergence was found in 16 of the 28 industries during 1993-2001, and in 18 of the 100 industries during 1997-2001. We estimated convergence's welfare effects, including those on followers' global value-added share, relative wage, imported share of consumption, and follower and leader welfare. Estimates of technological convergence effects are robust across three alternative welfare-equation estimators.

Consistent with our analytical results, convergence increases followers' global production shares and relative wages. The implication is that follower competitiveness and relative wage would be substantially lower in the absence of technological convergence. We also find significant effects of absolute TFP growth on both leader and follower welfare, underscoring the welfare-enhancing effect of technological progress. However, no significant effect of technological convergence is found on terms of trade. We recognize that lack of industry-level relative price data may be a potential reason for the insignificant terms-of-trade effect.

Since the 1990s, deepening world trade liberalization has greatly facilitated technology transfers between high- and low-income economies, speeding followers' technological "catch-up". The present study shows convergence improves both leader and follower's welfare, which appears to recommend such liberalization policies as trade-barrier reductions and open foreign-investment regimes would bring long-run benefits to both leaders and followers. In addition, technological progress is found to be significant in welfare determination, which implies productivity-enhancing investments, such as in R&D or in human capital, are essential to competitiveness- and welfare-improvement for all countries. Our study has its limitation. Many economic factors, for example public infrastructure and institutional reform, may influence both technological convergence and national welfare. Linkages between technology, trade, and economic growth likely are conditional on the quantity and quality of public-good investments. The present study is limited to the investigation of technological convergence's consequences, while taking the causes of convergence as given. Interactions between technological convergence and trade liberalization can be further explored with time-series data on relative prices, and public-good and R&D investments.

3.9 Endnotes

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[1] If there are increasing returns to scale at the level of national industries, then countries with larger industry outputs will have higher measured TFP even if technology is identical (Harrigan 1999, p.268).

[2] Relaxing the assumption of constant fixed cost complicates the analysis but does not affect our basic results.

[3] Note that complete factor price equalization requires convergence in both fixed cost and marginal cost. Here, marginal cost convergence reduces the technological and wage gap.

[4] If both fixed and marginal costs converge, the follower's global production share and relative wage will rise, while its imported share of consumption falls. Terms of trade remain unchanged in both countries. However, both countries benefit from the increased number of goods.

[5] The terms "technological" and "productivity" convergence are used synonymously.

[6] Recall in our theoretical model that a country's technological level is measured by its labor productivity (x/l or x^*/l^*). However, technological level is measured empirically here by total factor productivity (based on inputs of both capital and labor) rather than by labor productivity. The latter does not allow one to identify the separate influences of technology and capital growth (Bernard and Jones 1996b).

[7] To avoid perfect multicollinearity between $\Delta ln(LTFP_i)$ and η_{0i}, we employ industry dummy variables classified at a more aggregate industry level. See Results and Discussion section for more details.

[8] Estimates of equation (3.4) can be used to decompose both absolute and relative TFP growth of followers.

[9] Difference between $\Delta ln(LTFP_{ci})$ and $\Delta ln(RTFP_{ci})$ is the leader's productivity growth rate, which is perfectly collinear with the industry dummy variable, ϕ_{0i}. We therefore, as in equation (3.9), employ industry dummy variables at a more aggregate level.

[10] U.S. industrial correspondences between ISIC Revision 2 and Revision 3 are taken from U.S. Bureau of Census. We assume this correspondence is applicable to every nation. Some countries' data are available for certain years in both revisions, which enable us to test the average difference between the data reported in Revision 3 and

those converted, through the U.S. industry correspondences, from Revision 2 to Revision 3. Results of t-tests indicate that none of the data differences in value-added, employment, or gross fixed capital formation is significantly different from zero at the 5% significance level. Hence, we apply to other countries the U.S. correspondences between the two revisions.

[11] Manufacturing value-added price index and output price index are computed as the ratio of current to constant manufacturing value added; gross-fixed-capital-formation price index is computed as the ratio of current to constant gross fixed capital formation in the aggregate economy; and the consumer price index (CPI) of the aggregate economy is used to deflate wages.

[12] We follow Hall *et al.*'s (1988) procedure to obtain base-year capital stock data. Given that I_{t_0} is base-year investment, initial capital stock K_{t_0} equals $I_{t_0}/(d+g)$, where g is pre-sample annual growth rate of new capital. Country-specific pre-sample capital growth rates are derived as the average annual growth rates of gross fixed capital formation in the aggregate economy during the 10-year pre-sample period (WDI 2005). We set the depreciation rate (d) at 8% per year.

[13] The import (export) price index is calculated as the ratio of current to constant imports (exports) of goods and services in the aggregate economy.

[14] The 26 industries where U.S. is the second technological leader are ISIC1511, 1514, 1520, 1551, 1553, 1712, 1729, 1730, 2102, 2109, 2423, 2429, 2610, 2692, 2695, 2710, 2813, 2893, 2914, 2923, 3140, 3150, 3190, 3230, 3311, 3313. U.S. production data are unavailable in 10 of 128 industries (ISIC 1820, 2212, 2213, 2219, 2310, 2320, 2330, 3710, 3720, 3999).

[15] Carree, Klomp, and Thurik (2000) also found inter-industry differences in labor productivity convergence across manufacturing industries in 18 OECD countries during 1972-1992.

[16] As in equation (3.10), we employ 3-digit industry dummies in equation (3.9).

Table 3.1. Estimates of the Value-Added Equation
(Dependent Variable: Log of Value-Added Per Worker, 1993-2001)

Independent Variable	Estimates	
Log of capital per labor	0.201***	(39.36)
Log of employment	0.048***	(11.65)

Country-Specific Intercepts			**Time-Specific Intercepts**		
Australia	0.751***	(9.65)	1993	-0.025	(-0.84)
Austria	0.456***	(6.19)	1994	0.012	(0.43)
Colombia	0.716***	(8.87)	1995	-0.007	(-0.24)
Cyprus	0.271***	(3.27)	1996	----	
Denmark	0.350***	(4.68)	1997	0.046*	(1.88)
Ecuador	-1.377***	(-18.77)	1998	0.029	(1.20)
Eritrea	-0.247***	(-3.23)	1999	0.035	(1.45)
Ethiopia	-0.569***	(-7.37)	2000	0.050**	(2.06)
Finland	0.430***	(5.87)	2001	0.063**	(2.35)
France	0.359***	(4.73)			
India	-0.466***	(-6.29)			
Indonesia	-0.782***	(-10.54)			
Iran	-0.141*	(1.93)			
Italy	0.466***	(6.33)			
Japan	0.660***	(8.88)			
Jordan	-0.013	(-0.17)			
Korea	0.668***	(9.18)			
Kuwait	-0.269***	(-2.93)			
Malawi	-1.564***	(-17.45)			
Malaysia	-0.025	(-0.31)			
Malta	0.373***	(4.88)			
Mexico	0.171**	(2.30)			
Mongolia	-2.001***	(-25.46)			
Norway	0.449***	(6.15)			
Oman	-0.350***	(-4.65)			
Panama	-0.186**	(-2.41)			
Portugal	-0.020	(-0.28)			
Singapore	0.240***	(3.23)			
Spain	0.479***	(6.53)			
Sri Lanka	-0.399***	(-5.07)			
Thailand	-0.194**	(-2.15)			
Tunisia	----				
Turkey	0.526***	(7.17)			
United Kingdom	0.472***	(6.38)			
United States	0.964***	(12.94)			

Industry-Specific Intercepts

ISIC Code			*ISIC Code*			*ISIC Code*		
1511	7.663***	(72.21)	2222	7.513***	(67.03)	2922	7.686***	(67.84)
1512	7.510***	(71.21)	2230	8.214***	(72.52)	2923	7.872***	(68.41)
1513	7.479***	(70.85)	2310	7.828***	(60.42)	2924	7.824***	(69.11)
1514	8.015***	(76.41)	2320	9.066***	(75.32)	2925	7.699***	(69.86)

Table 3.1. (Continued.)

Industry-Specific Intercepts								
ISIC Code			*ISIC Code*			*ISIC Code*		
1520	7.887***	(74.62)	2330	7.428***	(34.85)	2926	7.602***	(66.30)
1531	7.942***	(73.83)	2411	8.264***	(70.94)	2927	7.624***	(66.56)
1532	8.272***	(67.82)	2412	8.150***	(69.33)	2929	7.755***	(68.53)
1533	8.031***	(75.80)	2413	8.356***	(70.14)	2930	7.759***	(69.10)
1541	7.459***	(66.91)	2421	8.550***	(74.56)	3000	8.079***	(70.26)
1542	7.957***	(72.58)	2422	8.146***	(72.87)	3110	7.748***	(68.85)
1543	7.903***	(70.61)	2423	8.329***	(78.45)	3120	7.839***	(69.19)
1544	7.879***	(69.04)	2424	8.262***	(73.83)	3130	7.911***	(69.25)
1549	7.801***	(68.64)	2429	7.987***	(71.23)	3140	7.825***	(70.06)
1551	8.683***	(81.27)	2430	8.188***	(67.17)	3150	7.633***	(67.91)
1552	7.947***	(74.55)	2511	7.968***	(74.19)	3190	7.643***	(67.63)
1553	8.827***	(80.50)	2519	7.564***	(68.11)	3210	7.834***	(66.89)
1554	8.127***	(75.22)	2520	7.574***	(66.62)	3220	8.216***	(71.69)
1600	8.938***	(85.35)	2610	7.747***	(68.86)	3230	7.674***	(66.06)
1711	7.480***	(65.17)	2691	7.472***	(70.23)	3311	7.846***	(70.94)
1712	7.516***	(66.78)	2692	7.812***	(69.35)	3312	7.810***	(68.43)
1721	7.453***	(67.43)	2693	7.594***	(67.55)	3313	8.023***	(70.56)
1722	7.522***	(71.27)	2694	8.526***	(78.65)	3320	7.704***	(68.55)
1723	7.353***	(71.12)	2695	7.682***	(68.25)	3330	7.611***	(71.69)
1729	7.507***	(67.06)	2696	7.526***	(67.35)	3410	8.112***	(68.59)
1730	7.395***	(71.61)	2699	7.925***	(70.35)	3420	7.497***	(67.95)
1810	7.261***	(66.09)	2710	8.008***	(68.70)	3430	7.701***	(68.55)
1820	7.384***	(65.36)	2720	7.996***	(68.99)	3511	7.646***	(67.98)
1911	7.620***	(72.60)	2731	7.518***	(65.67)	3512	7.603***	(67.62)
1912	7.324***	(71.54)	2732	7.498***	(68.09)	3520	7.793***	(73.34)
1920	7.376***	(67.50)	2811	7.579***	(68.09)	3530	7.981***	(72.71)
2010	7.492***	(66.92)	2812	7.747***	(69.27)	3591	7.839***	(59.30)
2021	7.532***	(66.02)	2813	7.855***	(66.26)	3592	7.662***	(65.04)
2022	7.376***	(66.70)	2891	7.503***	(65.93)	3599	7.660***	(63.03)
2023	7.269***	(71.34)	2892	7.618***	(69.25)	3610	7.438***	(67.13)
2029	7.363***	(65.70)	2893	7.678***	(69.99)	3691	7.751***	(71.45)
2101	7.863***	(67.34)	2899	7.616***	(67.47)	3692	7.579***	(72.66)
2102	7.733***	(68.38)	2911	7.864***	(69.62)	3693	7.634***	(72.86)
2109	7.776***	(68.64)	2912	7.831***	(69.45)	3694	7.496***	(66.78)
2211	8.006***	(70.91)	2913	7.737***	(63.73)	3699	7.563***	(68.32)
2212	8.022***	(70.21)	2914	7.806***	(70.43)	3710	7.964***	(67.94)
2213	8.149***	(65.66)	2915	7.855***	(70.25)	3720	7.619***	(64.05)
2219	7.763***	(65.89)	2919	7.651***	(68.51)	3999	7.711***	(63.87)
2221	7.643***	(67.64)	2921	7.698***	(68.02)			

$R^2 =$ 0.736
$N =$ 13578
F test: H_0: $b_{0c} = b_0 \quad \forall c$ F (34, 13406)=478.55*** Reject H_0

*** indicates significance at 1%; ** indicates significance at 5%; * indicates significance at 10%.
Numbers in parentheses are t-statistic of the coefficients.
Dummy variables of country Tunisia and year 1996 are dropped to avoid perfect multicollinearity.

Table 3.2. Productivity Leaders in 128 Manufacturing Industries

Industry and ISIC code	Productivity leader	Average Annual TFP growth rate (%)	
		The Leader	Followers
Sample A (1993-2001)			
1511 Processing/preserving of meat	Korea	1.57	0.70
1512 Processing/preserving of fish	United States	3.99	-0.26
1513 Processing/preserving of fruits and vegetables	United States	4.96	0.83
1514 Vegetable and animal oils and fats	Japan	4.89	-0.34
1520 Dairy products	Korea	6.14	3.07
1531 Grain mill products	United States	1.25	0.08
1533 Prepared animal feeds	United States	2.67	-0.19
1542 Sugar	Korea	8.13	0.50
1551 Distilling, rectifying and blending of spirits	Turkey	8.03	-2.06
1552 Wines	United States	2.53	4.14
1553 Malt liquors and malt	Korea	9.73	-0.30
1554 Soft drinks; mineral waters	Japan	1.47	0.91
1600 Tobacco products	United States	13.71	3.23
1722 Carpets and rugs	United States	1.51	1.76
1723 Cordage, rope, twine and netting	United States	3.38	1.16
1730 Knitted and crocheted fabrics and articles	Korea	3.81	-2.38
1911 Tanning and dressing of leather	United States	3.07	-0.40
1912 Luggage, handbags, etc.; saddlery & harness	United States	4.46	2.41
2023 Wooden containers	Korea	5.98	1.02
2423 Pharmaceuticals, medicinal chemicals, etc.	Singapore	2.43	2.51
2511 Rubber tyres and tubes	Turkey	3.74	1.10
2691 Pottery, china and earthenware	United States	2.54	2.79
2694 Cement, lime and plaster	United States	7.47	2.47
3330 Watches and clocks	United States	4.31	-0.09
3520 Railway/tramway locomotives & rolling stock	United States	4.29	0.79
3530 Aircraft and spacecraft	United States	5.96	3.33
3692 Musical instruments	United States	3.05	-1.30
3693 Sports goods	United States	2.20	4.07
Sample B (1997-2001)			
1532 Starches and starch products	United States	-0.34	4.31
1541 Bakery products	United States	3.50	1.89
1543 Cocoa, chocolate and sugar confectionery	United States	5.00	5.60
1544 Macaroni, noodle and similar products	United States	-12.48	-7.08
1549 Other food products n.e.c.	United States	4.11	2.68
1711 Textile fibre preparation; textile weaving	Turkey	59.02	0.70
1712 Finishing of textiles	Australia	-4.50	-0.71
1721 Made-up textile articles, except apparel	United States	2.89	-0.03
1729 Other textiles n.e.c.	Finland	7.00	-0.77
1810 Wearing apparel, except fur apparel	United States	2.69	-1.41
1820 Dressing & dyeing of fur; processing of fur	Japan	9.90	-1.91
1920 Footwear	United States	2.03	-1.49
2010 Sawmilling and planing of wood	France	3.88	4.11

Table 3.2. (Continued)

Industry and ISIC code		Productivity leader	Average Annual TFP growth rate (%)	
			The Leader	Followers
2021	Veneer sheets, plywood, particle board, etc.	United States	0.84	-1.61
2022	Builders' carpentry and joinery	United States	4.14	-0.64
2029	Other wood products; articles of cork/straw	United States	2.82	2.42
2101	Pulp, paper and paperboard	United States	4.68	6.56
2102	Corrugated paper and paperboard	Australia	8.64	0.94
2109	Other articles of paper and paperboard	Turkey	-8.29	0.03
2211	Publishing of books and other publications	Japan	0.17	1.52
2212	Publishing of newspapers, journals, etc.	Turkey	2.90	1.66
2213	Publishing of recorded media	France	-1.86	0.04
2219	Other publishing	Italy	15.27	2.70
2221	Printing	Turkey	6.73	1.18
2222	Service activities related to printing	United States	-0.36	-2.60
2230	Reproduction of recorded media	Japan	6.78	-4.51
2310	Coke oven products	Korea	-19.90	6.37
2320	Refined petroleum products	Korea	-7.97	7.31
2330	Processing of nuclear fuel	Japan	-18.00	----
2411	Basic chemicals, except fertilizers	United States	-6.47	2.00
2412	Fertilizers and nitrogen compounds	United States	-8.69	-3.97
2413	Plastics in primary forms; synthetic rubber	United States	-1.55	-3.47
2421	Pesticides and other agro-chemical products	United States	-5.67	-8.73
2422	Paints, varnishes, printing ink and mastics	United States	3.15	-0.96
2424	Soap, cleaning & cosmetic preparations	United States	1.43	5.01
2429	Other chemical products n.e.c.	Turkey	20.16	-5.91
2430	Man-made fibres	United States	-2.11	-5.46
2519	Other rubber products	United States	0.42	2.39
2520	Plastic products	United States	2.39	1.74
2610	Glass and glass products	Korea	13.33	1.91
2692	Refractory ceramic products	Finland	3.31	1.35
2693	Structural non-refractory clay; ceramic products	Norway	3.90	-0.58
2695	Articles of concrete, cement and plaster	Australia	1.42	-1.20
2696	Cutting, shaping & finishing of stone	United States	4.70	-1.57
2699	Other non-metallic mineral products n.e.c.	United States	2.21	-3.87
2710	Basic iron and steel	Korea	8.90	-5.37
2720	Basic precious and non-ferrous metals	United States	-1.06	2.90
2731	Casting of iron and steel	United States	0.89	1.28
2732	Casting of non-ferrous metals	United States	3.24	0.91
2811	Structural metal products	United States	2.57	0.21
2812	Tanks, reservoirs and containers of metal	Turkey	0.92	-0.34
2813	Steam generators	Japan	1.07	1.39
2891	Metal forging/pressing/stamping/roll-forming	United States	-0.13	-5.99
2892	Treatment & coating of metals	Mexico	-7.70	-2.33
2893	Cutlery, hand tools and general hardware	Australia	2.75	-0.60
2899	Other fabricated metal products n.e.c.	United States	2.17	1.09
2911	Engines & turbines(not for transport equip.)	United States	9.92	5.31
2912	Pumps, compressors, taps and valves	United States	2.30	0.14
2913	Bearings, gears, gearing & driving elements	United States	-1.07	0.33
2914	Ovens, furnaces and furnace burners	Japan	-34.20	-1.64
2915	Lifting and handling equipment	United States	2.37	1.01

Table 3.2. (Continued)

Industry and ISIC code		Productivity leader	Average Annual TFP growth rate (%)	
			The Leader	Followers
2919	Other general purpose machinery	United States	0.71	-1.16
2921	Agricultural and forestry machinery	United States	-0.35	-0.60
2922	Machine tools	United States	-1.87	0.72
2923	Machinery for metallurgy	Finland	-25.50	-1.89
2924	Machinery for mining & construction	United States	-0.73	2.61
2925	Food/beverage/tobacco processing machinery	United States	-0.64	-0.43
2926	Machinery for textile, apparel and leather	United States	-0.80	-4.89
2927	Weapons and ammunition	Japan	3.53	4.96
2929	Other special purpose machinery	United States	-0.79	1.60
2930	Domestic appliances n.e.c.	United States	-0.69	1.93
3000	Office, accounting and computing machinery	United States	-0.53	-0.72
3110	Electric motors, generators and transformers	United States	-0.01	1.60
3120	Electricity distribution & control apparatus	United States	1.52	1.42
3130	Insulated wire and cable	United States	2.08	0.01
3140	Accumulators, primary cells and batteries	Australia	8.55	1.34
3150	Lighting equipment and electric lamps	United States	2.25	1.86
3190	Other electrical equipment n.e.c.	United States	2.93	-0.02
3210	Electronic valves, tubes, etc.	United States	-6.26	3.53
3220	TV/radio transmitters; line comm. apparatus	Turkey	-0.37	-2.32
3230	TV and radio receivers and associated goods	Turkey	11.15	1.30
3311	Medical, surgical and orthopaedic equipment	Singapore	13.09	3.37
3312	Measuring/testing/navigating appliances, etc.	United States	1.46	3.77
3313	Industrial process control equipment	Norway	-17.39	0.52
3320	Optical instruments & photographic equipment	United States	-2.35	2.88
3410	Motor vehicles	United States	-3.16	0.13
3420	Automobile bodies, trailers & semi-trailers	Australia	-0.39	5.56
3430	Parts/accessories for automobiles	Austria	10.17	-1.15
3511	Building and repairing of ships	Japan	-2.53	-0.19
3512	Building/repairing of pleasure/sport. boats	United States	2.28	2.33
3591	Motorcycles	United States	6.16	-1.60
3592	Bicycles and invalid carriages	Japan	3.55	5.13
3599	Other transport equipment n.e.c.	Korea	-3.40	6.11
3610	Furniture	United States	2.97	2.74
3691	Jewellery and related articles	United States	0.18	2.45
3694	Games and toys	United States	-4.04	-2.29
3699	Other manufacturing n.e.c.	United States	1.51	-2.45
3710	Recycling of metal waste and scrap	Korea	-2.02	-1.57
3720	Recycling of non-metal waste and scrap	Norway	-11.24	-0.62
3999	Total manufacturing	Turkey	11.42	1.87

Only data on Japan are available in time series for the industry of ISIC 2330.

Table 3.3. Test of Productivity Convergence
Dependent Variable: Average Growth Rate of Follower's Relative TFP

Industry and ISIC code	Intercepts		Followers' relative TFP at the initial year		Rate of convergence (%)
Sample A (1993-2001)					
1511 Processing/preserving of meat	-0.061***	(-2.86)	-0.073***	(-3.16)	10.48
1512 Processing/preserving of fish	-0.067***	(-2.61)	-0.031	(-1.17)	
1513 Processing/preserving of fruits and vegetables	-0.082***	(-2.96)	-0.038*	(-1.72)	4.43
1514 Vegetable and animal oils and fats	-0.082***	(-3.09)	-0.025	(-1.30)	
1520 Dairy products	-0.096***	(-4.33)	-0.069***	(-3.72)	9.53
1531 Grain mill products	-0.073**	(-2.34)	-0.036**	(-2.19)	4.11
1533 Prepared animal feeds	-0.077***	(-2.86)	-0.054**	(-2.11)	6.75
1542 Sugar	-0.115***	(-3.58)	-0.022	(-1.42)	
1551 Distilling, rectifying and blending of spirits	-0.167***	(-6.70)	-0.058***	(-3.49)	7.53
1552 Wines	-0.048*	(-1.72)	-0.046***	(-3.18)	5.65
1553 Malt liquors and malt	-0.133***	(-6.67)	-0.056***	(-2.68)	7.12
1554 Soft drinks; mineral waters	-0.075***	(-2.91)	-0.051***	(-3.13)	6.32
1600 Tobacco products	-0.172***	(-7.30)	-0.045***	(-3.55)	5.41
1722 Carpets and rugs	-0.049**	(-2.01)	-0.046***	(-2.76)	5.52
1723 Cordage, rope, twine and netting	-0.054**	(-2.24)	-0.035*	(-1.78)	4.09
1730 Knitted and crocheted fabrics and articles	-0.093***	(-5.16)	-0.053***	(-2.60)	6.68
1911 Tanning and dressing of leather	-0.054***	(-2.61)	-0.030	(-1.33)	
1912 Luggage, handbags, etc.; saddlery & harness	-0.021	(-0.72)	-0.0004	(-0.02)	
2023 Wooden containers	-0.059***	(-2.96)	-0.015	(-0.81)	
2423 Pharmaceuticals, medicinal chemicals, etc.	-0.029	(-0.68)	-0.015	(-0.74)	
2511 Rubber tyres and tubes	-0.064***	(-2.63)	-0.044**	(-2.00)	5.34
2691 Pottery, china and earthenware	-0.045	(-1.46)	-0.053*	(-1.87)	6.73
2694 Cement, lime and plaster	-0.070***	(-4.29)	-0.065***	(-2.84)	8.81
3330 Watches and clocks	-0.077***	(-2.64)	-0.046	(-1.50)	
3520 Railway/tramway locomotives & rolling stock	-0.064**	(-2.11)	-0.044	(-1.20)	
3530 Aircraft and spacecraft	-0.050	(-1.24)	-0.047	(-0.74)	
3692 Musical instruments	-0.080**	(-2.53)	-0.078	(-1.50)	
3693 Sports goods	-0.010	(-0.33)	-0.031	(-1.16)	
R^2	0.446				
N= 558					
F test for identical intercepts across industries:	$F(27, 502)=2.15$***		Reject H_0		

Table 3.3. (Continued)

Industry and ISIC code	Intercepts		Followers' relative TFP at the initial year		Rate of convergence (%)
Sample B (1997-2001)					
1532 Starches and starch products	0.011	(0.19)	-0.03	(-0.72)	
1541 Bakery products	-0.071*	(-1.67)	-0.048	(-1.49)	
1543 Cocoa, chocolate and sugar confectionery	-0.026	(-0.59)	-0.029	(-0.85)	
1544 Macaroni, noodle and similar products	-0.02	(-0.44)	-0.058**	(-1.93)	6.36
1549 Other food products n.e.c.	-0.039	(-0.94)	-0.021	(-0.71)	
1711 Textile fibre preparation; textile weaving	-0.593***	(-23.61)	-0.043	(-1.12)	
1712 Finishing of textiles	0.053	(1.01)	0.014	(0.32)	
1721 Made-up textile articles, except apparel	-0.03	(-0.89)	-0.001	(-0.02)	
1729 Other textiles n.e.c.	-0.098***	(-3.17)	-0.028	(-1.04)	
1810 Wearing apparel, except fur apparel	-0.068**	(-2.01)	-0.03	(-1.02)	
1820 Dressing & dyeing of fur; processing of fur	-0.181***	(-4.46)	-0.059**	(-2.17)	6.49
1920 Footwear	-0.016	(-0.36)	0.021	(0.47)	
2010 Sawmilling and planing of wood	-0.058*	(-1.84)	-0.076***	(-2.91)	8.68
2021 Veneer sheets, plywood, particle board, etc.	-0.027	(-0.87)	-0.005	(-0.12)	
2022 Builders' carpentry and joinery	-0.049	(-1.44)	-0.002	(-0.05)	
2029 Other wood products; articles of cork/straw	-0.046	(-1.43)	-0.070**	(-2.19)	7.84
2101 Pulp, paper and paperboard	0.037	(0.94)	0.019	(0.57)	
2102 Corrugated paper and paperboard	-0.102***	(-3.15)	-0.046	(-1.04)	
2109 Other articles of paper and paperboard	0.019	(0.42)	-0.076	(-1.62)	
2211 Publishing of books and other publications	-0.024	(-0.49)	-0.031	(-0.89)	
2212 Publishing of newspapers, journals, etc.	-0.049	(-0.59)	-0.017	(-0.46)	
2213 Publishing of recorded media	-0.017	(-0.18)	-0.032	(-0.41)	
2219 Other publishing	-0.220***	(-2.62)	-0.071	(-1.20)	
2221 Printing	-0.072***	(-2.65)	-0.033	(-0.99)	
2222 Service activities related to printing	0.016	(0.42)	0.037	(0.74)	
2230 Reproduction of recorded media	-0.171***	(-3.80)	-0.077**	(-2.15)	8.85
2310 Coke oven products	0.138*	(1.92)	-0.061**	(-2.14)	6.75
2320 Refined petroleum products	0.135*	(1.67)	-0.039	(-0.60)	
2330 Processing of nuclear fuel	---				
2411 Basic chemicals, except fertilizers	0.023	(0.51)	-0.062*	(-1.65)	6.84
2412 Fertilizers and nitrogen compounds	0.028	(0.54)	-0.026	(-0.40)	
2413 Plastics in primary forms; synthetic rubber	-0.033	(-0.97)	-0.025	(-0.61)	

Table 3.3. (Continued)

Industry and ISIC code	Intercepts		Followers' relative TFP at the initial year		Rate of convergence (%)
2421 Pesticides and other agro-chemical products	-0.016	(-0.25)	0.01	(0.26)	
2422 Paints, varnishes, printing ink and mastics	-0.098**	(-2.03)	-0.065	(-1.32)	
2424 Soap, cleaning & cosmetic preparations	-0.021	(-0.50)	-0.04	(-1.52)	
2429 Other chemical products n.e.c.	-0.281***	(-9.32)	-0.032	(-0.97)	
2430 Man-made fibres	-0.077	(-1.33)	-0.077	(-0.89)	
2519 Other rubber products	-0.011	(-0.32)	-0.045	(-1.26)	
2520 Plastic products	-0.052*	(-1.78)	-0.070**	(-2.19)	7.94
2610 Glass and glass products	-0.147***	(-5.46)	-0.058**	(-1.93)	6.36
2692 Refractory ceramic products	-0.035	(-0.81)	-0.015	(-0.44)	
2693 Structural non-refractory clay; ceramic products	-0.021	(-0.56)	-0.004	(-0.10)	
2695 Articles of concrete, cement and plaster	-0.031	(-1.02)	-0.007	(-0.23)	
2696 Cutting, shaping & finishing of stone	-0.032	(-0.95)	0.048	(1.30)	
2699 Other non-metallic mineral products n.e.c.	-0.06	(-1.14)	0.002	(0.02)	
2710 Basic iron and steel	-0.178***	(-5.70)	-0.072*	(-1.63)	8.10
2720 Basic precious and non-ferrous metals	0.038	(0.99)	-0.003	(-0.06)	
2731 Casting of iron and steel	-0.013	(-0.36)	-0.023	(-0.66)	
2732 Casting of non-ferrous metals	-0.037	(-0.98)	-0.04	(-0.50)	
2811 Structural metal products	-0.037	(-1.13)	-0.019	(-0.54)	
2812 Tanks, reservoirs and containers of metal	-0.069	(-1.39)	-0.079	(-1.30)	
2813 Steam generators	-0.121	(-1.26)	-0.163	(-1.37)	
2891 Metal forging/pressing/stamping/roll-forming	-0.06*	(-1.81)	-0.002	(-0.06)	
2892 Treatment & coating of metals	0.108*	(1.89)	0.041	(1.02)	
2893 Cutlery, hand tools and general hardware	-0.038	(-1.17)	-0.006	(-0.17)	
2899 Other fabricated metal products n.e.c.	-0.054	(-1.52)	-0.061	(-1.52)	
2911 Engines & turbines(not for transport equip.)	-0.128**	(-2.26)	-0.075*	(-1.63)	8.49
2912 Pumps, compressors, taps and valves	-0.074**	(-2.26)	-0.082**	(-2.23)	9.46
2913 Bearings, gears, gearing & driving elements	-0.039	(-0.43)	-0.129	(-0.62)	
2914 Ovens, furnaces and furnace burners	0.299***	(5.43)	-0.022	(-0.55)	
2915 Lifting and handling equipment	-0.01	(-0.29)	0.009	(0.18)	
2919 Other general purpose machinery	-0.037	(-1.05)	-0.026	(-0.68)	
2921 Agricultural and forestry machinery	-0.057	(-1.21)	-0.075	(-1.36)	
2922 Machine tools	-0.02	(-0.52)	-0.054	(-1.48)	
2923 Machinery for metallurgy	0.224**	(2.49)	-0.009	(-0.14)	

Table 3.3. (Continued)

Industry and ISIC code	Intercepts		Followers' relative TFP at the initial year		Rate of convergence (%)
2924 Machinery for mining & construction	-0.036	(-0.74)	-0.100*	(-1.65)	11.97
2925 Food/beverage/tobacco processing machinery	0.013	(0.37)	0.014	(0.42)	
2926 Machinery for textile, apparel and leather	0.023	(0.46)	0.05	(0.62)	
2927 Weapons and ammunition	0.004	(0.09)	-0.008	(-0.33)	
2929 Other special purpose machinery	-0.014	(-0.31)	-0.064	(-0.95)	
2930 Domestic appliances n.e.c.	-0.022	(-0.50)	-0.056	(-1.29)	
3000 Office, accounting and computing machinery	-0.063	(-1.10)	-0.094	(-1.19)	
3110 Electric motors, generators and transformers	-0.007	(-0.21)	-0.04	(-0.91)	
3120 Electricity distribution & control apparatus	-0.056	(-1.52)	-0.079**	(-2.02)	9.05
3130 Insulated wire and cable	-0.066*	(-1.64)	-0.072	(-1.36)	
3140 Accumulators, primary cells and batteries	-0.074**	(-2.09)	-0.003	(-0.08)	
3150 Lighting equipment and electric lamps	-0.027	(-0.46)	-0.031	(-0.43)	
3190 Other electrical equipment n.e.c.	-0.056*	(-1.66)	-0.039	(-1.12)	
3210 Electronic valves, tubes, etc.	0.014	(0.20)	-0.109	(-1.25)	
3220 TV/radio transmitters; line comm. apparatus	-0.048	(-1.54)	-0.033	(-1.44)	
3230 TV and radio receivers and associated goods	-0.099***	(-3.25)	-0.001	(-0.03)	
3311 Medical, surgical and orthopaedic equipment	-0.128***	(-3.89)	-0.046	(-1.31)	
3312 Measuring/testing/navigating appliances, etc.	-0.029	(-0.59)	-0.065	(-1.27)	
3313 Industrial process control equipment	0.144*	(1.88)	-0.055	(-0.49)	
3320 Optical instruments & photographic equipment	-0.045	(-1.00)	-0.083***	(-2.68)	9.62
3410 Motor vehicles	0.05	(1.07)	0.021	(0.43)	
3420 Automobile bodies, trailers & semi-trailers	0.003	(0.11)	-0.055*	(-1.65)	6.07
3430 Parts/accessories for automobiles	-0.147***	(-5.36)	-0.066**	(-1.96)	7.32
3511 Building and repairing of ships	-0.029	(-0.73)	-0.063	(-1.60)	
3512 Building/repairing of pleasure/sport. boats	-0.008	(-0.21)	-0.02	(-0.29)	
3591 Motorcycles	-0.138	(-0.96)	-0.119	(-0.44)	
3592 Bicycles and invalid carriages	-0.032	(-0.60)	-0.075	(-1.13)	
3599 Other transport equipment n.e.c.	0.075	(1.36)	-0.024	(-0.50)	
3610 Furniture	-0.062**	(-2.09)	-0.079***	(-2.77)	9.04
3691 Jewellery and related articles	0.0001	(0.00)	-0.027	(-0.82)	
3694 Games and toys	0.034	(0.69)	0.015	(0.39)	
3699 Other manufacturing n.e.c.	-0.034	(-1.01)	0.008	(0.20)	
3710 Recycling of metal waste and scrap	-0.025	(-0.23)	-0.043	(-0.28)	

Table 3.3. (Continued)

Industry and ISIC code	Intercepts		Followers' relative TFP at the initial year		Rate of convergence (%)
3720 Recycling of non-metal waste and scrap	0.159**	(2.01)	0.0004	(0.00)	
3999 Total manufacturing	-0.095***	(-2.86)	0.001	(0.03)	
R^2	0.519				
N= 1753					
F test for identical intercepts across industries:	F (98, 1555)=7.68***	Reject H_0			

*** indicates significance at 1%; ** indicates significance at 5%; * indicates significance at 10%.
Numbers in parentheses are t-statistic of the coefficients.
Only data on Japan are available in time series for the industry of ISIC 2330.

Table 3.4. Effects of Technological Convergence

3.4a. Estimates of Followers' Global Value-Added Share Equation
Dependent Variable: Average Growth Rate of Followers' Global Value-Added Share

Independent variable	OLS	FGLS (grouped by industry)	FGLS (grouped by country)
Sample A (1993-2001)			
Average growth rate of relative TFP over 1993-2001	0.926*** (90.29)	0.987*** (189.93)	0.929*** (101.30)
Average growth rate of global capital share over 1993-2001	0.202*** (24.69)	0.203*** (49.65)	0.200*** (27.52)
Average growth rate of global labor share over 1993-2001	0.838*** (77.69)	0.846*** (207.12)	0.838*** (105.08)
Country fixed effects F test: H_0: $b_{0c} = b_0 \ \forall c$	F (32, 506) = 0.76	$\chi^2(31) = 2.92$	$\chi^2(31) = 20.94$
Industry fixed effects F test: H_0: $b_{0i} = b_0 \ \forall i$	F (16, 506) = 64.73***	χ^2 (16) = 11252.32***	χ^2(16) = 1290.77***
R^2 N= 558	0.978		
LR Test. H_0: No groupwise heteroskedasticity		χ^2(27) = 733.27***	χ^2(32) = 34.56

3.4a. (Continued)

Independent variable	OLS	FGLS (grouped by industry)	FGLS (grouped by country)
Sample B (1997-2001)			
Average growth rate of relative TFP over 1997-2001	0.716*** (69.92)	0.949*** (118.97)	0.670*** (64.92)
Average growth rate of global capital share over 1997-2001	0.146*** (11.09)	0.189*** (25.91)	0.140*** (10.14)
Average growth rate of global labor share over 1997-2001	0.891*** (75.39)	0.856*** (130.17)	0.876*** (71.71)
Country fixed effects F test: H_0: $b_{0c} = b_0\ \forall c$	F (26, 1672) = 0.97	χ^2(26) = 4.77	χ^2(26) = 43.75**
Industry fixed effects F test: H_0: $b_{0i} = b_0\ \forall i$	F (51, 1672) = 12.26***	χ^2(50) =2856.59***	χ^2(50) = 611.89***
R^2	0.896		
N= 1753			
LR Test. H_0: No groupwise heteroskedasticity		χ^2(98) = 2544.03***	χ^2(26) = 144.47***

3.4b. Estimates of Followers' Relative Wage Equation
Dependent Variable: Average Growth Rate of Followers' Relative Wage

Independent variable	OLS	FGLS (grouped by industry)	FGLS (grouped by country)
Sample A (1993-2001)			
Average growth rate of relative TFP over 1993-2001	0.229*** (8.08)	0.239*** (11.01)	0.208*** (10.15)
Average growth rate of relative capital intensity over 1993-2001	0.110*** (5.25)	0.095*** (5.54)	0.064*** (3.85)
Country fixed effects F test: H_0: $b_{0c} = b_0 \ \forall c$	F (29, 456) = 8.50***	χ^2(29) = 466.07***	χ^2(29) = 551.93***
Industry fixed effects F test: H_0: $b_{0i} = b_0 \ \forall i$	F (27, 456) = 4.11***	χ^2(27) = 132.73***	χ^2(27) = 451.42***
R^2	0.588		
N= 516			
LR Test. H_0: No groupwise heteroskedasticity		χ^2(27) = 179.67***	χ^2(30) = 445.67***

3.4b. (Continued)

Independent variable	OLS	FGLS (grouped by industry)	FGLS (grouped by country)
Sample B (1997-2001)			
Average growth rate of relative TFP over 1997-2001	0.159*** (9.48)	0.162*** (13.45)	0.144*** (11.05)
Average growth rate of relative capital intensity over 1997-2001	-0.011 (-0.80)	0.002 (0.22)	0.011 (1.00)
Country fixed effects F test: H_0: $b_{0c} = b_0\ \forall c$	F (25, 1530) = 8.97***	χ^2(25) = 605.88***	χ^2(25) = 402.34***
Industry fixed effects F test: H_0: $b_{0i} = b_0\ \forall i$	F (97, 1530) = 3.66***	χ^2(97) = 451.58***	χ^2(97) = 949.09***
R^2 N= 1656	0.326		
LR Test. H_0: No groupwise heteroskedasticity		χ^2(98) = 972.76***	χ^2(25) = 1680.09***

3.4c. Estimates of Followers' Imported-Share-of-Consumption Equation
Dependent Variable: Average Growth Rate of Followers' Imported Consumption Share

Independent variable	OLS	FGLS (grouped by industry)	FGLS (grouped by country)
Sample A (1993-2001)			
Average growth rate of relative TFP over 1993-2001	-0.903*** (-3.38)	-0.861*** (-4.61)	-0.917*** (-4.85)
Average growth rate of relative capital over 1993-2001	0.146 (0.71)	0.150 (1.00)	0.061 (0.40)
Average growth rate of relative labor over 1993-2001	-1.051*** (-4.90)	-0.975*** (-6.76)	-0.963*** (-5.72)
Country fixed effects F test: H_0: $b_{0c} = b_0 \ \forall c$	F (22, 248) = 2.00***	χ^2(22) = 68.80***	χ^2(22) =78.04***
Industry fixed effects F test: H_0: $b_{0i} = b_0 \ \forall i$	F (27, 248) = 1.55**	χ^2(26) = 46.11***	χ^2(26) = 65.32***
R^2	0.338		
N=301			
LR Test. H_0: No groupwise heteroskedasticity		χ^2(27) = 178.92***	χ^2(22) = 89.60***

3.4c. (Continued)

Independent variable	OLS	FGLS (grouped by industry)	FGLS (grouped by country)
Sample B (1997-2001)			
Average growth rate of relative TFP over 1997-2001	-0.687*** (-5.96)	-0.519*** (-9.13)	-0.551*** (-5.99)
Average growth rate of relative capital over 1997-2001	0.123 (1.06)	0.152*** (2.16)	0.073 (0.72)
Average growth rate of relative labor over 1997-2001	-0.690*** (-6.64)	-0.709*** (-13.54)	-0.641*** (-7.42)
Country fixed effects F test: H_0: $b_{0c} = b_0\ \forall c$	F (23, 1021) = 2.78***	χ^2(23) = 311.40***	χ^2(23) = 80.16***
Industry fixed effects F test: H_0: $b_{0i} = b_0\ \forall i$	F (88, 1021) = 2.97***	χ^2(87) = 264.18***	χ^2(87) = 342.63***
R^2 N= 1136	0.294		
LR Test. H_0: No groupwise heteroskedasticity		χ^2(88) = 1066.65***	χ^2(23) =200.91***

3.4d. Estimates of Followers' Welfare Equation
Dependent Variable: Average Growth Rate of Followers' Welfare

Independent variable	OLS	FGLS (grouped by industry)	FGLS (grouped by country)
Sample A (1993-2001)			
Average growth rate of followers' TFP over 1993-2001	0.447 (1.51)	0.543*** (3.87)	0.602*** (5.24)
Average growth rate of relative TFP over 1993-2001	0.223 (0.76)	0.073 (0.54)	0.012 (0.11)
Average growth rate of followers' capital over 1993-2001	0.203*** (3.26)	0.230*** (5.58)	0.197*** (5.50)
Average growth rate of followers' labor over 1993-2001	0.888*** (14.29)	0.845*** (22.07)	0.841*** (21.56)
Country fixed effects F test: H_0: $b_{0c} = b_0 \; \forall c$	$F(22, 258) = 2.62$***	$\chi^2(22) = 159.44$***	$\chi^2(22) = 101.32$***
Industry fixed effects F test: H_0: $b_{0i} = b_0 \; \forall i$	$F(16, 258) = 0.98$	$\chi^2(15) = 16.17$	$\chi^2(15) = 36.28$***
R^2 $N = 301$	0.672		
LR Test. H_0: No groupwise heteroskedasticity		$\chi^2(27) = 319.21$***	$\chi^2(22) = 336.11$***

3.4d. (Continued)

Independent variable	OLS	FGLS (grouped by industry)	FGLS (grouped by country)
Sample B (1997-2001)			
Average growth rate of followers' TFP over 1997-2001	0.498*** (12.56)	0.517*** (16.02)	0.516*** (17.16)
Average growth rate of relative TFP over 1997-2001	0.022 (0.65)	0.029 (1.04)	0.011 (0.48)
Average growth rate of followers' capital over 1997-2001	0.075*** (3.15)	0.111*** (6.36)	0.074*** (3.16)
Average growth rate of followers' labor over 1997-2001	0.800*** (35.84)	0.806*** (42.72)	0.864*** (42.37)
Country fixed effects F test: H_0: $b_{0c} = b_0 \ \forall c$	F (24, 1120) = 6.91***	χ^2(24) = 262.77***	χ^2(24) = 177.05***
Industry fixed effects F test: H_0: $b_{0i} = b_0 \ \forall i$	F (46, 1120) = 1.56**	χ^2(45) = 91.49***	χ^2(45) = 76.32***
R^2	0.727		
N= 1195			
LR Test. H_0: No groupwise heteroskedasticity		χ^2(88) =607.01***	χ^2(24) =551.25***

3.4e. Estimates of Leaders' Welfare Equation
Dependent Variable: Average Growth Rate of the Leader's Welfare

Independent variable	OLS	FGLS (grouped by industry)	FGLS (grouped by country)
Sample A (1993-2001)			
Average growth rate of leader's TFP over 1993-2001	0.599*** (9.66)	0.658*** (17.50)	0.511*** (13.39)
Average growth rate of relative TFP over 1993-2001	-0.013 (-1.12)	0.001 (0.16)	0.003 (0.56)
Average growth rate of leader's capital over 1993-2001	0.134*** (3.40)	0.143*** (5.36)	0.223*** (7.78)
Average growth rate of leader's labor over 1993-2001	0.767*** (12.79)	0.843*** (24.72)	0.734*** (19.89)
Country fixed effects F test: H_0: $b_{0c} = b_0 \ \forall c$	F (23, 273) = 0.85	χ^2(23) = 29.84	χ^2(23) = 32.18*
Industry fixed effects F test: H_0: $b_{0i} = b_0 \ \forall i$	F (16, 273) =32.91***	χ^2(15) = 1470.52***	χ^2(15) = 1797.96***
R^2	0.972		
N= 317			
LR Test. H_0: No groupwise heteroskedasticity		χ^2(27) = 520.79***	χ^2(23) = 321.43***

3.4e. (Continued)

Independent variable	OLS	FGLS (grouped by industry)	FGLS (grouped by country)
Sample B (1997-2001)			
Average growth rate of leader's TFP over 1997-2001	0.475*** (30.53)	0.517*** (50.28)	0.504*** (41.08)
Average growth rate of relative TFP over 1997-2001	-0.006 (-0.64)	0.001 (0.67)	-0.006 (-1.27)
Average growth rate of leader's capital over 1997-2001	0.130*** (5.02)	0.146*** (8.17)	0.127*** (5.39)
Average growth rate of leader's labor over 1997-2001	0.980*** (29.17)	0.948*** (54.72)	0.970*** (36.62)
Country fixed effects F test: H_0: $b_{0c} = b_0 \ \forall c$	F (25, 1151) = 0.69	$\chi^2(25) = 11.07$	$\chi^2(25) = 63.37$***
Industry fixed effects F test: H_0: $b_{0i} = b_0 \ \forall i$	F (46, 1151) = 26.86***	$\chi^2(45) = 11542.03$***	$\chi^2(45) = 2030.57$***
R^2	0.934		
N= 1227			
LR Test. H_0: No groupwise heteroskedasticity		$\chi^2(88) = 3052.59$***	$\chi^2(25) = 492.48$***

In tables 3.4a – 3.4e, *** indicates significance at 1% level; ** indicates significance at 5% level; * indicates significance at 10% level. Numbers in parentheses are t-statistics.

Table 3.5. Decomposition of Relative TFP Growth Rate and Identification of Technological Convergence Effects on Follower Welfare

	Average growth rate of relative TFP over 1993-2001	Relative TFP growth rate induced by technological convergence	Relative TFP growth rate induced by non-convergence factors
Sample A (1993-2001)			
Mean	-3.54%	4.02%	-7.57%
Global-value-added-share effect			
OLS	-3.28%	3.72%	-7.01%
FGLS (grouped by industry)	-3.49%	3.97%	-7.47%
FGLS (grouped by country)	-3.29%	3.73%	-7.03%
Relative-wage effect			
OLS	-0.81%	0.92%	-1.73%
FGLS (grouped by industry)	-0.85%	0.96%	-1.81%
FGLS (grouped by country)	-0.74%	0.84%	-1.57%
Imported-share-of-consumption effect			
OLS	3.20%	-3.63%	6.84%
FGLS (grouped by industry)	3.05%	-3.46%	6.52%
FGLS (grouped by country)	3.25%	-3.69%	6.94%
Real-income effect			
OLS	-1.58%	1.80%	-3.38%
FGLS (grouped by industry)	-1.92%	2.18%	-4.11%
FGLS (grouped by country)	-1.97%	2.24%	-4.22%

Table 3.5. (Continued)

	Average growth rate of relative TFP over 1997-2001	Relative TFP growth rate induced by technological convergence	Relative TFP growth rate induced by non-convergence factors
Sample B (1997-2001)			
Mean	-1.36%	2.74%	-4.10%
<u>Global-value-added-share effect</u>			
OLS	-0.97%	1.96%	-2.94%
FGLS (grouped by industry)	-1.29%	2.60%	-3.89%
FGLS (grouped by country)	-0.91%	1.84%	-2.75%
<u>Relative-wage effect</u>			
OLS	-0.22%	0.44%	-0.65%
FGLS (grouped by industry)	-0.22%	0.44%	-0.66%
FGLS (grouped by country)	-0.20%	0.39%	-0.59%
<u>Imported-share-of-consumption effect</u>			
OLS	0.93%	-1.88%	2.82%
FGLS (grouped by industry)	0.71%	-1.42%	2.13%
FGLS (grouped by country)	0.75%	-1.51%	2.26%
<u>Real-income effect</u>			
OLS	-0.68%	1.36%	-2.04%
FGLS (grouped by industry)	-0.70%	1.42%	-2.12%
FGLS (grouped by country)	-0.70%	1.41%	-2.12%

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CHAPTER 4

GLOBAL PRODUCTIVITY DISTRIBUTION AND TRADE IN PROCESSED FOOD INDUSTRIES

4.1 Introduction

Significant and persistent differences in capital and skill intensity, size, and productivity have been observed among firms in the same, narrowly defined industries.[1] In an influential article, Melitz (2003) shows that trade liberalization in the presence of firm heterogeneity, the above noted differences among firms, will raise an industry's average productivity and cause intra-industry resource reallocation. More specifically, exposure to trade in an industry induces not only its high-productivity firms to enter foreign markets but also its low-productivity firms to exit the domestic market. The consequences include a truncation from below of the industry's productivity distribution, which increases its average productivity and a reallocation of resources and market share to high-productivity firms.

Empirical evidence on such trade-liberalization effects on an industry's productivity and resource reallocation can be found in Aw, Chung, and Roberts (2000), Pavcnik (2002), and Bernard and Jensen (2004). In her examination of plant productivity evolution following Chilean trade liberalization, Pavcnik (2002) finds that more productive plants have increased their shares of output in six out of eight sample industries. Furthermore, the reallocation of resources from the less to more efficient producers is responsible for two-thirds of the growth in Chilean manufacturing productivity. In the case of U.S. manufacturing industries, Bernard and Jensen (2004) report that increase in exports are associated with resource reallocation from the less to more efficient plants. From 1983 to 1992, over 40 percent of the productivity growth in the U.S. manufacturing industries can be attributed to the intra-industry reallocation effect. See Feenstra (2006) for a review of evidence on the gains from trade.

The objective of this article is to investigate the impact of trade liberalization on the productivity and spatial distribution of processed food industries. Agriculture and processed food industries account for a large share of developing countries' GDP and employment (World Development Indicators 2005; United Nations' UNIDO 2005). Since the 1994 Uruguay Round Agreement on Agriculture (URAA), these industries have been subjected to considerable tariff reductions, and world agricultural exports have increased from $500 billion in 1994 to $852 billion in 2005 (International Trade Statistics, World Trade Organization).[2] Under trade liberalization, the possibility of low-productivity firms' death and resource shifts in favor of high-productivity firms have important consequences for developing countries' employment, wages, and income growth. We draw on Melitz's (2003) and Helpman, Melitz, and Yeaple's (2004) contribution to investigate the trade liberalization-productivity distribution linkage in a cross-country setting. Our application considers heterogeneity across countries within each processed food industry and tests the hypothesis that the mean of the global productivity distribution shifts to the right following multilateral trade liberalization.[3] In addition, we examine the consequent intra-industry redistribution of market shares and resources among countries.

Our empirical analysis includes 1993-2000 data from 34 countries (11 high-income, 23 low-income) on 5 processed food industries, defined on the basis of ISIC (Revision 3) 4-digit classification. We employ a value-added function allowing for country-, industry-, and time-specific effects to estimate total factor productivity (TFP) levels, assuming variable returns to scale (Harrigan 1999). The productivity distribution of each industry is approximated by nonparametric kernel density estimators (Sala-i-Martin 2006; Beaudry, Collard, and Green 2005; Jones 1997). We then quantify the effects of trade liberalization on global productivity distribution by examining the evolution of alternative quantiles, e.g., mean, median. Our results suggest that the mean and other quantiles of the global productivity distribution shift to the right with liberalized international trade. Moreover, countries with faster productivity growth benefit from trade liberalization by acquiring a larger share of global markets and resources.

4.2 Conceptual Framework

We draw on the firm-heterogeneity model of Melitz (2003) and Helpman, Melitz, and Yeaple (2004) to investigate the mean shifts in the global productivity distribution and the intra-industry consequences of trade reform. For this purpose, we briefly illustrate their monopolistic competition framework, where firms differ in productivity levels. In equilibrium, an industry's productivity distribution and its resource allocation depend on trade exposure. Then, we generalize these results for the cross-country setting.

A continuum of firms produce differentiated goods in the same industry. Each firm manufactures a differentiated variety due to monopolistic competition. With a constant-elasticity-of-substitution (CES) utility function of the Dixit-Stiglitz type, the demand function of firm *i*'s variety is $x_i = Ap_i^{-\varepsilon}$, where x_i is the quantity and p_i is the price, A is a measure of the demand level, and $\varepsilon = 1/(1-\alpha) > 1$ is the demand elasticity.[4] Firm *i* draws its productivity, θ_i, only after it incurs a fixed entry cost, f_E. Upon observing its draw, a firm decides whether or not to produce. If it chooses to produce, it then bears fixed production cost, f_D. If the firm chooses to export, it has to bear the additional fixed cost of f_X per foreign market. The latter allows for high-productivity firms' self-selection into foreign markets (Bernard and Jensen 1999). Helpman, Melitz, and Yeaple (2004) indicate that f_X can be considered as the costs of forming a distribution and servicing network in a foreign country. In addition, an iceberg trade cost, τ, which includes transportation costs and trade barriers, is incurred for the shipment of every variety between any two countries, i.e., $\tau > 1$ units are shipped for one unit to arrive.

Let c_i / θ_i be the *i*-th firm's variable production cost per unit of output, where c_i measures the cost of resources, which equals the wage rate when labor is the only input into production. When serving the domestic market, firm *i* maximizes its profit by charging a price $p_i = c_i / \alpha\theta_i$, yielding an operating profit $\pi_D^i = \theta_i^{\varepsilon-1} c_i^{1-\varepsilon} B - f_D$, where $B = (1-\alpha) A \alpha^{\varepsilon-1}$. On the other hand, firm *i* can acquire additional operating profits from exporting to a foreign country ℓ, $\pi_X^i = \tau^{1-\varepsilon}\theta_i^{\varepsilon-1} c_i^{1-\varepsilon} B^{\ell} - f_X$, where $B^{\ell} = (1-\alpha) A^{\ell} \alpha^{\varepsilon-1}$. The model is solved by setting π_D^i and π_X^i to zero each, and ensuring free entry, i.e., expected value of a firm equals the fixed entry costs (f_E). The equilibrium distribution of productivity in the industry is characterized by the cut-off productivity levels θ_D and

θ_X to break-even in domestic and foreign markets, respectively. Moreover, the higher the average industry profits, the larger is the domestic-market productivity cut-off θ_D (Melitz 2003).

Figure 4.1 depicts π_D^i and π_X^i for the case in which $B = B^\ell$. In this figure, both profit functions are increasing: high-productivity firms achieve larger profits in both domestic sales and exports relative to low-productivity firms. The profit function π_D^i is steeper than π_X^i due to trade cost τ. Figure 4.1 shows that firms with productivity level lower than θ_D will exit the industry, because they gain negative profits from either domestic sales or exports. Firms with intermediate productivities, between θ_D and θ_X, will attain the highest profits by serving only domestic markets. High-productivity firms, with $\theta > \theta_X$, serve both domestic and foreign markets.

Now consider the two-fold effects of multilateral trade liberalization, which proportionally reduces trade costs τ for all countries. The first is the increase in profits from exporting due to the reduction in trade cost. Firms that had productivity levels just below the cutoff θ_X now find exports profitable. Alternatively, the profit function π_X^i rotates to the left, reducing the export-productivity cut-off to $\theta_X' < \theta_X$. Consequently, more firms become exporters and each firm expands its exports, which are referred to as changes in the extensive and intensive margins, respectively. The second effect is on firm profits in the domestic market. The higher average industry profit due to export market opportunities, made possible by trade reform, increases the break-even productivity in the domestic market, $\theta_D' > \theta_D$. In figure 4.1, this effect rotates π_D^i to the right. In other words, changes in extensive and intensive margins, the death of low-productivity firms and increased export activity, respectively, reallocate market shares to high-productivity firms. Bernard and Jensen (2004) find that as much as 40 percent of the productivity growth in U.S. manufacturing industries can be attributed to this intra-industry resource reallocation effect.

Claim

Trade liberalization induced exit of low-productivity firms truncates from below an industry's productivity distribution and increases average industry productivity.

Proof

Suppose that firms draw their productivity from a raw productivity distribution $G(\theta)$. Firms that draw a productivity level above θ_D produce, and therefore, the equilibrium cumulative productivity distribution is: $F(\theta) = P(\Theta \leq \theta \mid \Theta \geq \theta_D) = \dfrac{G(\theta) - G(\theta_D)}{1 - G(\theta_D)}$, which implies the truncated probability density function (pdf) is $f(\theta) = \dfrac{g(\theta)}{1 - G(\theta_D)}$, where $g(\theta)$ is the pdf of $G(\theta)$.

By definition, the cumulative density of the *p*-th quantile of the truncated distribution, θ^p, is $F(\theta^p) = \dfrac{G(\theta^p) - G(\theta_D)}{1 - G(\theta_D)} = p$, where $p \in [0,1]$, which yields $G(\theta^p) = p + (1-p)G(\theta_D)$. As trade liberalization raises θ_D and $G(\theta_D)$, $G(\theta^p)$ rises, leading to an increase in θ^p. That is, any quantile value of the truncated distribution rises with the increase of domestic cutoff θ_D, and therefore, the mass of the truncated productivity distribution shifts to the right.

The mean of the truncated distribution $F(\theta)$ is defined as $E(\theta) = \frac{\int_{\theta_D}^{+\infty} \theta g(\theta) d\theta}{1 - G(\theta_D)}$.

The first derivative of $E(\theta)$ with respect to θ_D is:

$$
\begin{aligned}
\frac{dE(\theta)}{d\theta_D} &= \frac{[\int_{\theta_D}^{+\infty} \theta g(\theta) d\theta]'[1 - G(\theta_D)] + g(\theta_D)\int_{\theta_D}^{+\infty} \theta g(\theta) d\theta}{[1 - G(\theta_D)]^2} \\
&= \frac{g(\theta_D)[\int_{\theta_D}^{+\infty} \theta g(\theta) d\theta + G(\theta_D)\theta_D - \theta_D]}{[1 - G(\theta_D)]^2} \\
&= \frac{g(\theta_D)}{1 - G(\theta_D)} \cdot [E(\theta) - \theta_D] \\
&> 0
\end{aligned}
\quad . \tag{4.1}
$$

That is, trade liberalization increases the industry's average productivity by forcing the low-productivity firms to exit. *Q.E.D.*

The impact of trade liberalization on global productivity distribution can also be shown by figure 4.2. In figure 4.2, $G(\theta)$ is the raw productivity distribution from which firms draw their productivity. However, only firms with productivity levels above domestic cutoff θ_D can make positive profit and thus, operate in the market, which yields a truncated productivity distribution with a mean of E_1. Trade liberalization increases the domestic cutoff to θ_D', forcing the low-productivity firms to exit the industry, and thus, improving the average productivity of the surviving firms to E_2. As a result, trade liberalization raises the industry average productivity even if the raw productivity distribution does not change. This increase is in addition to the shift in the raw productivity distribution, $G(\theta)'$, in figure 4.2, arising from factors such as the industry's research and development investment, infrastructure or international technology transfers. Given the new raw distribution, the average industry productivity will then shift to E_3.

Our application of the model to processed food industries treats each country as a firm. That is, we work with heterogeneity across countries than that in the intra-country dimension and explore resource reallocation within an industry, but across countries. By suppressing firm differences within a country, we may be overlooking high-productivity firms inside low-productivity countries, but it does not diminish the fact that such countries have the greatest concentration of low-productivity firms. Moreover, few studies have access to internationally comparable cross-country, firm-level databases with a time series (Tybout 2000).

4.3 Econometric Framework and Procedure

In our empirical application, we estimate total factor productivity (TFP) from an econometric specification of a value-added function (Miller and Upadhyay 2002; Harrigan 1999; Bernard and Jones 1996). Details of the assumed value-added structure, which permits variable returns-to-scale, are provided in Appendix III. The approach in Appendix III allows hypothesis tests about the robustness of cross-country TFP measures (Miller and Upadhyay 2002; Bernard and Jones 1996; Baumol, Nelson, and Wolff 1994; Ark and Pilat 1993). The internationally comparable database described in the next section permits cross-country comparisons of TFP levels.

With industry- and country-specific time-series data on TFP levels, we can estimate each industry's global productivity distribution for each year using a nonparametric kernel density function (Sala-i-Martin 2006; Beaudry, Collard, and Green 2005; Jones 1997). We follow the convention in the literature to use the bandwidth $w=1.059\sigma n^{-1/5}$, where σ is the standard deviation of log-TFP, and n is the number of observations. For each productivity distribution, we then approximate its first moment and p-th percentiles (p = 10, 25, 50, 75, and 90). Thus for each industry, we use time-series estimates of percentiles to capture the shifts of productivity distribution.

In the previous section, we showed how trade liberalization shifts the mean of the global productivity distribution to the right, resulting in higher average industry productivity. The latter is due to the truncation from below of the productivity distribution, which forces the low-productivity firms to exit the industry. To empirically identify the effect of trade liberalization on the industry's productivity distribution, we specify the estimated first moment and alternative percentile values as a function of a measure of trade liberalization:

(4.2) $$PROD_{jt} = \beta_{0\,jt} + \beta_1 LOGTRADE_{jt} + \beta_2 YEAR_t + \mu_{1\,jt},$$

where $PROD_{jt}$ denotes the estimated first moment or any of the five quantiles in industry j at period t; $LOGTRADE_{jt}$ denotes log of aggregate trade value in industry j at period t, a measure of industry j's degree of trade liberalization.[5] Thus, the coefficient β_1 indicates the effect of trade liberalization on productivity distribution, and we expect its estimate to take a positive sign. As indicated in figure 4.2, the productivity distribution itself may shift over time due to non-trade-liberalization factors, which we capture in two alternative ways. The first is the use of the intercepts, $\beta_{0\,jt}$, which allow for productivity to vary across industries and time due to differences in production technologies, institutional environment, or other unobserved heterogeneity. We therefore include two-way fixed and random effects in equation (4.2), and employ Hausman test to choose between the two estimators. The other approach we use is to introduce a time-trend, $YEAR_t$, to account for the effect on productivity distribution of these non-trade-liberalization factors. The term $\mu_{1\,jt}$ in equation (4.2) represents a random disturbance term.

In our application to the cross-country setting, trade liberalization should reallocate market share and resources to high-productivity countries within an industry. For each industry, we use the difference between a country's productivity and the estimated global average to measure the former's relative productivity status. That is, $PRODIFF_{ijt} = PROD_{ijt} - PROD_{jt}$, where $PROD_{ijt}$ is country *i*'s productivity in industry *j* at period *t*, $PROD_{jt}$ is industry *j*'s global productivity average. In other words, $PRODIFF_{ijt}$ is country *i*'s productivity relative to the industry average in time *t*. Then, a country's higher productivity relative to the global average should induce global resource and market shares in its direction. Let $GSHARE_{ijt}$ be the indicator of country *i*'s global market share or resource share in industry *j* at period *t*, where the market share is measured by global value-added share and global output share, and the resource share is measured by global capital share and global labor share. Thus, $\Delta GSHARE_{ijt}$ denotes the annual growth rate of $GSHARE_{ijt}$ from the previous year:

(4.3) $$\mathit{\Delta GSHARE}_{ijt} = \ln \mathit{GSHARE}_{ij,t} - \ln \mathit{GSHARE}_{ij,t-1}\,.$$

To capture the reallocation of market shares and resources due to trade liberalization, we specify $\mathit{\Delta GSHARE}_{ijt}$ as follows:

(4.4) $$\mathit{\Delta GSHARE}_{ijt} = \gamma_0 + \gamma_1 \mathit{\Delta PRODIFF}_{ijt} + \gamma_2 \mathit{YEAR}_t + \mu_{2ijt}\,,$$

where $\mathit{\Delta PRODIFF}_{ijt}$ denotes the annual growth rate of country *i*'s productivity relative to that of the industry average productivity; YEAR_t denotes a time-trend; and μ_{2ijt} is a random disturbance term. We expect the estimate of γ_1 to take a positive sign. However, the variable $\Delta \mathit{PRODIFF}_{ijt} = \Delta\left(\mathit{PROD}_{ijt} - \mathit{PROD}_{jt}\right)$ captures two opposing effects on global shares: the positive impact from productivity growth, $\mathit{\Delta PROD}_{ijt}$ and the negative one from mean-shifts in the global productivity distribution, $\mathit{\Delta PROD}_{jt}$. The latter effect causes every country to lose a part of its share of global markets and resources as their least productive firms exit following trade liberalization. So, countries that overcome the negative, mean-shifting effects, i.e., productivity growth faster than that in the global average, gain market and resource shares. As in equation (4.2), we consider fixed- and random-time effects in equation (4.4). Given the growth-growth specification, the cross-country and –industry heterogeneity cancel out in equation (4.4). Therefore, the impact of trade liberalization on reallocation of global market shares and resources can be identified as $-\widehat{\beta_1} \cdot \widehat{\gamma_1} \cdot \overline{\mathit{\Delta LOGTRADE}_{jt}}$, where $\overline{\mathit{\Delta LOGTRADE}_{jt}}$ denotes the average annual growth rate of $\mathit{LOGTRADE}_{jt}$ over 1993-2000, and $\widehat{\beta_1}$ and $\widehat{\gamma_1}$ denote respectively the estimates of β_1 and γ_1 in equations (4.2) and (4.4).[6]

4.4 Data

The United Nations Industrial Development Organization's (UNIDO) Industrial Statistical Database (INDSTAT4 2005) provides cross-country data on manufacturing industry value-added, employment, gross fixed capital formation, and output. Data on 5 processed food industries, based on ISIC (Revision 3) 4-digit classifications in 34 countries from 1993 to 2000, are taken from INDSTAT4.[7] Among the 34 countries, 11 are developed (Austria, Denmark, Finland, Ireland, Italy, Japan, Norway, Portugal, Spain, United Kingdom, United States), and 23 are developing economies (Columbia, Cyprus, Ecuador, Eritrea, Ethiopia, India, Indonesia, Iran, Jordan, Korea, Kuwait, Malawi, Malaysia, Malta, Mexico, Mongolia, Oman, Panama, Singapore, Sri Lanka, Thailand, Tunisia, Turkey). Data for some countries are available only in selected years, so data classified at ISIC Revision 2 are used to complete the series. In U.S. industries, correspondences between ISIC Revision 2 and Revision 3 are taken from U.S. Bureau of Census; we assume this correspondence is applicable to every nation.[8] As data availability varies by country and industry, we have an unbalanced data panel. Except for employment, which is expressed in labor units, production data are measured in INDSTAT4 in current local currencies. To render them internationally comparable, we first convert cross-country and -industry data to constant 2000 local currencies by using the corresponding price index from the World Bank's 2005 World Development Indicators (WDI). We then convert them to constant 2000 U.S. dollars by using the purchasing power parity (PPP) conversion factors from 2005 WDI.[9]

With data on annual gross fixed capital formation, we construct capital stock as a function of past investment flows, following the standard perpetual inventory equation with declining-balance depreciation (Crego *et al.* 1998; Hall *et al.* 1988):

(4.5) $$K_t = (1-d)K_{t-1} + I_t ,$$

where I_t is gross fixed capital formation in year *t*, K_t is capital stock at end of year *t*, and d is depreciation rate.[10]

Bilateral trade data, expressed in nominal U.S. dollars, come originally from the COMTRADE database (United Nations) and are reclassified into ISIC (Revision 3) 4-digit-level industries. We adopt country-specific import and export price indexes from WDI and convert them to constant 2000 U.S. dollars.[11]

4.5 Results and Discussion

Estimates of the determinants of country-level TFP, equation (III.3), are presented in table 4.1. Log of capital per unit labor is significant at the 1 percent level and indicates the elasticity of value added with respect to capital is 0.250. The statistically insignificant coefficient of the log of employment (-0.024) suggests food industries exhibit constant returns to scale. In an earlier study, Chan-Kang, Buccola, and Kerkvliet (1999) find modest scale economies in the U.S. food processing industry. The elasticity of value-added with respect to employment, implicit in the coefficients of employment and capital per unit labor in table 4.1, is 0.726 (equation III.3). Processed food industries appear, that is, to be labor intensive, consistent with earlier analysis (e.g., Melton and Huffman 1995).

Cross-country and -industry TFP estimates are derived for each year with the estimates in table 4.1 using equation III.4 in appendix III. An F-test rejects, at the 1 percent level, the null hypothesis of identical technologies across countries [F(33, 1050), 45.70]. Thus, TFP estimates show significant variation in level and growth rate across countries, among which the U.S. is the technological leader in each of the five processed food industries. Previous studies have found U.S. TFP levels in most processed food industries to be high as well (Harrigan 1997; Chan-Kang, Buccola, and Kerkvliet 1999).

With cross-country, -industry, and -time TFP levels, we employ kernel density techniques to approximate the global productivity distributions for each food industry in every time period. Densities are computed using a Gaussian kernel at each estimating point. Cumulative density then allows estimation of alternative percentile values, and first and second moments of the distribution. Table 4.2 presents the mean and standard deviation of each industry's productivity distribution in 1993 and 2000. In all the five food industries, industry average productivity has risen during 1993-2000, and the average annual growth rate varies between 0.2 and 2.9 percent.

The estimates of equation (4.2), i.e., effects of trade liberalization on productivity distribution, are reported in table 4.3. Four sets of estimates are presented: industry-fixed effects; industry-random effects; industry- and time-fixed effects; and industry- and time-random effects. In most cases, the Hausman tests favor fixed-effects estimators as indicated by the chi-squared test statistics in table 4.3. In addition, F tests indicate evidence of industry- and time-specific effects. Hence, the following discussion focuses on the estimates with industry- and time-fixed effects.

The second column in table 4.3 corresponds to the trade-effects on the mean of the global productivity distribution. An industry's average productivity increases by 0.465 percent for every 1 percent increase in its global trade and this effect is statistically significant at the 1 percent level. Both industry- and time-specific effects are significant in the mean regression at the 1 and 10 percent levels, respectively. The R^2 of 91.3 percent suggests that our model well explains the variation in the mean of the global productivity distribution. The positive effect of an industry's global trade value on its average productivity is robust across four alternative estimates reported in table 4.3. However, the random-effects estimates of global trade effects on average industry productivity is about half of those from fixed-effect models. In general, our results are consistent with the firm-heterogeneity models that predict an increase in an industry's average industry productivity following trade liberalization. It is likely that low-productivity firms are forced to exit and, most probably, in low-productivity countries.

The third to the seventh columns in table 4.3 report the estimates of trade liberalization's effects on the various measures of global productivity distribution, i.e., 10^{th}, 25^{th}, 50^{th}, 75^{th} and 90^{th} percentiles. Except in the case of the 90^{th} percentile, our estimates show that the measures of global productivity distribution are positively and significantly affected by an increase in global trade. The elasticity of productivity with respect to global trade ranges from 0.300 to 0.715. Noteworthy is the elasticity of percentile productivity with respect to the global trade declines with the increase of quantiles, suggesting that facing trade liberalization, productivity improvement is faster in low-productivity countries than in their high-productivity counterparts. The latter result is consistent with the literature on productivity convergence. Earlier studies have found global productivity convergence in manufacturing industries. For example, Bernard and Jones (1996) indicate during 1970-1987, productivity convergence has taken place in manufacturing industry of 14 OECD countries with an annual convergence rate of 1.68%. Furthermore, the high-percentile productivity, e.g., 90th, may better respond to technological investments than trade liberalization.[12]

In table 4.3, F tests suggest the presence of industry-specific effects in each of the five percentile regressions, and that of time-specific effects in the 50th, 75th and 90th percentile equations. In these percentile regressions, the R^2 ranges from 58.1 to 95.5 percent. Note that our results are robust across the two fixed-effect estimates, with and without time-specific effects. Except for 10th and 90th percentile productivity regressions, Hausman tests favor fixed effects in other equations. In general, our results suggest that the shifts in the mean and other percentile values of the global productivity distribution, especially the left-tail, are strongly associated with the increase in global trade in processed food industries.

We present the results of cross-country reallocation of market shares and resources due to productivity growth relative to its global average in table 4.4. Three sets of estimates are reported: with time-fixed effects, time-random effects, and a time-trend. In the following, we focus on the results from the model with time-fixed effects, given their statistical significance. Note, however, the effects of relative productivity do not vary much across the three specifications reported in table 4.4.[13] Reallocation of market shares is measured by the annual growth rate in a country's global value-added share and its global output share. For every 1 percent growth in a country's productivity relative to the global average, its share in global value-added increases by 1.112 percent, and that in global output increases by 0.606 percent. Both of these effects are significant at the 1 percent level, confirming our claim that market shares will be reallocated toward countries with higher productivity growth than the global average. Note that our estimation of equation (4.4) explains 76.2 percent of the variation in global value-added share, and 36.7 percent of the variation in global output share.

The cross-country reallocation of production resources associated with the changes in the global productivity distribution, captured using annual growth rate in a country's global labor share and global capital share, is presented in the last two columns of table 4.4. Global labor share of a country increases by 0.173 percent for every 1 percent growth in its productivity relative to the global average. So, employment in processed food industries shifts due to differences in relative productivity growth. However, growth in a country's relative productivity does not significantly affect its global capital share in our results. The latter may arise if processed food industries are labor-intensive or capital's mobility is restricted. For instance, the gain from productivity growth may not be enough to release capital, whose returns may be bounded between salvage value and average market return on other investments.

Estimation of equations (4.2) and (4.4) enables us to decompose the change in global market shares and resources into those induced by relative TFP and non-TFP factors. The results are reported in table 4.5. Relative TFP changes have increased the developing countries' global value-added shares, output shares, and labor shares by 3.84, 2.09, and 0.60 percent per year, but decreased the developed countries' global value-added shares, output shares, and labor shares by 3.66, 1.99, and 0.57 percent annually. The relative TFP effect on capital growth, as noted earlier, is statistically non-significant. We then decompose the relative TFP effect into those attributable to trade and non-trade factors. Recall that trade liberalization reduces every country's global market and resource shares by forcing their least productive firms to exit the industry and improving the industry average productivity. Specifically, trade growth in processed food industries respectively reduces the countries' global value-added shares and output shares by 3.85 and 2.10 percent annually, and cut their labor shares by 0.60 percent per year. Note that the trade effects are invariant across countries since measures of global productivity distribution do not carry a country index. However, net changes in global market and resource shares differ between developed and developing countries due to non-trade TFP and non-TFP factors. In particular, the developing countries' productivity relative to the industry average has grown 3.45 percent per year during 1993-2001, while that of the developed countries has dropped by 3.30 percent annually, causing market shares and resources to be reallocated toward the developing countries. These results suggest that countries' TFP growth relative to the global average is a key determinant of intra-industry reallocation of market shares and resources. As the positive non-trade TFP effects more than makes up for the negative mean-shifting (trade) and non-TFP effects, the developing countries acquired larger shares in global value-added, output, and labor with an annual rate of 2.30, 3.86, and 1.30 percent, respectively. For the developed countries, however, negative non-trade TFP effects add to similar mean-shifting and non-TFP effects, lowering their share of global markets and resources.

4.6 Summary and Conclusions

In this article, we investigate the effects of trade liberalization on the global productivity distribution in processed food industries. For this purpose, we extend firm-heterogeneity models of international trade to a cross-country setting. The extension suggests that multilateral trade liberalization induces intra-industry reallocation of market shares and resources across countries. In particular, export market opportunities raise average industry profits, which in turn, increase the minimum productivity required to break-even in domestic markets. Thus, low-productivity firms are forced to exit an industry following trade liberalization, while resources and market shares are reallocated to high-productivity firms. Our application of the model to processed food industries considers heterogeneity across countries than that in the intra-country dimension. The macro focus allows us to explore reallocation of resources among countries with varying levels and growth rates of productivity in a given industry.

Data on 5 processed food industries in 34 developed and developing nations are assembled to estimate, through a value-added equation, cross-country and cross-industry productivity levels. Estimates indicate significant cross-country variation in productivity levels, with U.S. as the productivity leader in each of the five food industries. For each industry, we approximate the global productivity distribution in each year by using a nonparametric kernel density estimator. We then estimate the effects of trade liberalization on alternative quantiles of the global productivity distribution. More specifically, the first moment and alternative percentile values are used to represent the shifts of the global productivity distribution. We find that our estimates of trade-liberalization effects on such measures of global productivity distribution to be robust across alternative econometric specifications. The results suggest that trade liberalization significantly boosts an industry's average productivity and shifts to the right most of the percentile values of the global productivity distribution. Moreover, countries with faster productivity growth relative to the global average increase their shares of global value-added, output, and labor, implying TFP growth relative to the global average is a key determinant of intra-industry reallocation of market shares and resources.

Since the early 1990s, multilateral trade liberalization has greatly deepened the global integration of processed food production. Our study examines the evolution of global productivity distribution in processed food industries, its response to trade liberalization, and the intra-industry reallocation of market shares and resources among countries. Ceteris paribus, our results suggest that a liberalized trade regime can improve industry average productivity, and thus, the income and welfare of an economy. Moreover, intra-industry reallocation of market shares and resources substantially depends on countries' relative productivity growth. Nevertheless, countries with slower productivity growth, regardless of their average comparative advantage, face significant adjustments to employment and income following trade liberalization.

4.7 Endnotes

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[1] See Bernard and Jensen (1999), Eaton, Kortum, and Kramarz (2004), Helpman, Melitz, and Yeaple (2004), Helpman (2006), and Bernard *et al.* (2007).

[2] Under URAA, developed countries are to cut agricultural tariffs by 36% during six years following 1994 and developing countries are to reduce their agricultural tariffs by 24% during a ten-year period. Although the Doha round has temporarily stalled, the prospects for additional liberalization remain high.

[3] This assumption suppresses firm differences within a country, i.e., overlook the existence of high-productivity firms inside low-productivity countries. However, it does not diminish the fact that such countries have the greatest concentration of low-productivity firms.

[4] This form of demand function is derived from a CES utility function. $A = E / \int_{i \in I} p(i)^{1-\varepsilon} di$, where E is total expenditure on these differentiated goods, $p(i)$ is the consumer price of variety i, and I is the set of available varieties.

[5] We considered two alternatives for $LOGTRADE_{jt}$: one-period lag of global trade value and trade share of output. Also, we test the endogeneity of $LOGTRADE_{jt}$ in equation (4.2) using a Hausman test. See the Results and Discussion section for the outcomes of the above specification tests.

[6] In equation (4.4), $PRODIFF_{ijt} = PROD_{ijt} - PROD_{jt}$. Thus, $-\gamma_1$ indicates the effect of industry average productivity growth on global market-share and resource reallocation.

[7] Although there are 17 ISIC 4-digit processed food industries, we chose only 5 due to data availability. Most statistical studies implementing kernel density estimators use at least 25 observations in each time period to capture the underlying (productivity) distribution and its moments.

[8] Some countries' data are available for certain years in both revisions. These data enable us to test the average difference between the data reported in Revision 3 and those converted, from the U.S. industry correspondences, from Revision 2 to Revision 3. Results of t-tests indicate that none of the data differences in value-added, output, employment, or gross fixed capital formation is significantly different from zero at the 5% significance level. Hence, we apply to other countries the U.S. correspondences between the two revisions.

[9] Manufacturing value-added price index and output price index are computed as the ratio of current to constant manufacturing value added; and gross-fixed-capital-formation price index is computed as the ratio of current to constant gross fixed capital formation in the aggregate economy.

[10] We follow Hall *et al.*'s (1988) procedure to obtain base-year capital stock data. Given that I_{t0} is base-year investment, initial capital stock K_{t0} equals $I_{t0}/(d+g)$, where g is pre-sample annual growth rate of new capital. Country-specific pre-sample capital growth rates are derived as the average annual growth rates of gross fixed capital formation in the aggregate economy during the 10-year pre-sample period (2005 WDI). We set the depreciation rate (d) at 8% per year.

[11] The import (export) price index is calculated as the ratio of current to constant imports (exports) of goods and services in the aggregate economy.

[12] Employing the one-period lag of global trade value we find significant effects of trade liberalization on the 10th and 25th percentile productivity, and the first moment of productivity distribution in the industry-fixed-effect specifications. However, a Hausman test suggested that current trade value and the industry's productivity growth are not simultaneously determined. We also use trade share of output as an alternative measure of the degree of trade liberalization in an industry. Again, we find that the 10th and 25th percentile productivity are significantly improved by trade share of output.

[13] Fixed- and random-effects models yield the same coefficients on annual growth rate of relative productivity, and so, the Hausman statistics are close to zero in all four equations. Though F tests favor time-specific effects, using a time-trend instead does not change the coefficient on growth rate of relative productivity in any of the four equations.

Figure 4.1. Profits from Domestic Sales and from Exports

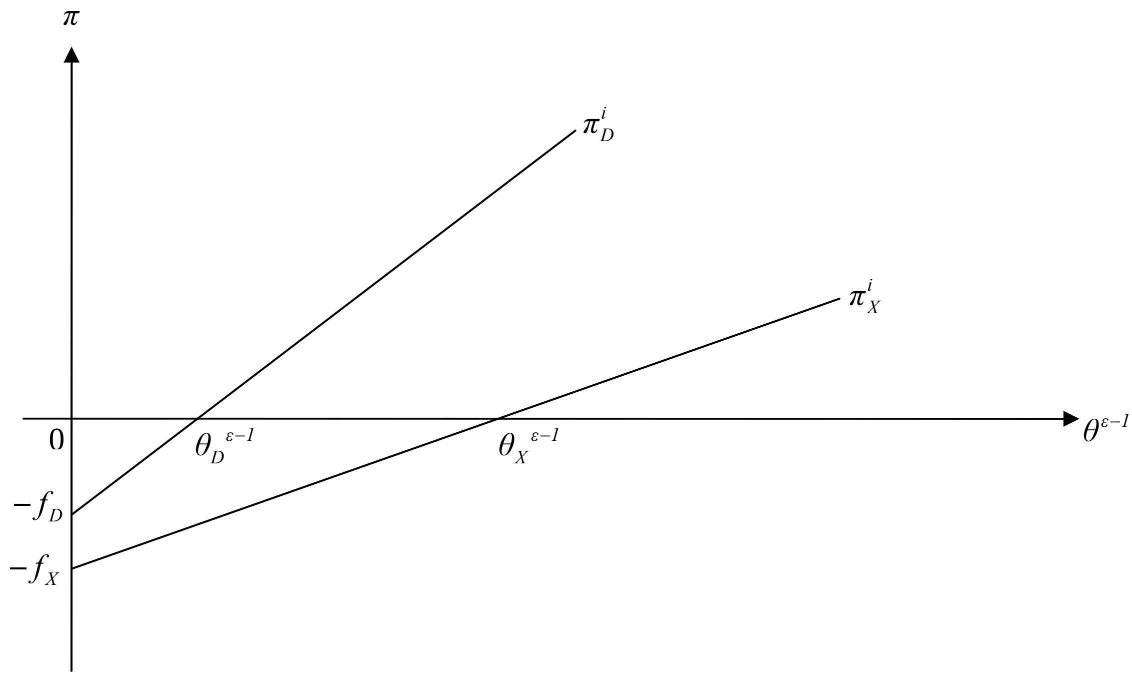

Figure 4.2. Global Productivity Distribution with Trade Liberalization

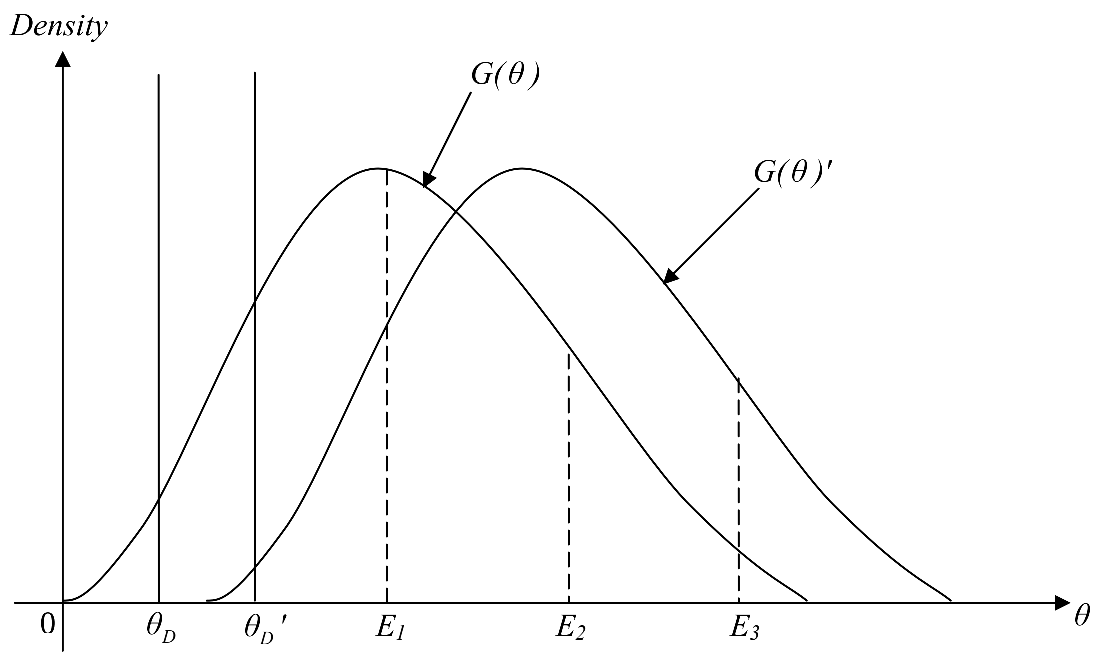

Table 4.1. Estimates of the Value-Added Equation
(Dependent Variable: Log of Value-Added Per Worker, 1993-2000)

Independent Variable	Estimates	
Log of capital per labor	0.250***	(11.51)
Log of employment	-0.024	(-1.38)

Country-Specific Intercepts			**Industry-Specific Intercepts**			**Time-Specific Intercepts**		
Austria	8.456***	(24.36)	1511	-0.232***	(-4.85)	1993	-0.098	(-1.57)
Colombia	8.991***	(26.46)	1512	-0.411***	(-7.67)	1994	-0.077	(-1.30)
Cyprus	8.174***	(25.87)	1513	-0.459***	(-9.21)	1995	-0.009	(-0.16)
Denmark	8.429***	(24.07)	1514	0.081*	(1.67)	1996	-0.025	(-0.41)
Ecuador	6.785***	(19.44)	1520	----		1997	0.061	(1.02)
Eritrea	7.143***	(21.87)				1998	-0.011	(-0.19)
Ethiopia	7.103***	(24.84)				1999	-0.021	(-0.35)
Finland	8.295***	(24.28)				2000	----	
India	7.626***	(21.42)						
Indonesia	7.742***	(21.78)						
Iran	8.080***	(21.91)						
Ireland	8.575***	(24.19)						
Italy	8.558***	(22.82)						
Japan	8.838***	(23.87)						
Jordan	7.714***	(25.23)						
Korea	8.617***	(23.61)						
Kuwait	7.852***	(24.94)						
Malawi	6.023***	(18.01)						
Malaysia	8.193***	(23.93)						
Malta	8.189***	(26.29)						
Mexico	8.029***	(21.62)						
Mongolia	5.685***	(15.73)						
Norway	8.186***	(23.41)						
Oman	7.573***	(21.45)						
Panama	8.004***	(25.23)						
Portugal	7.748***	(21.95)						
Singapore	7.975***	(24.37)						
Spain	8.504***	(23.53)						
Sri Lanka	7.909***	(27.24)						
Thailand	7.913***	(20.62)						
Tunisia	7.319***	(20.45)						
Turkey	8.736***	(25.11)						
United Kingdom	8.623***	(23.81)						
United States	9.225***	(24.16)						

$R^2 = 0.998$
$N = 1097$
F test: H_0: $b_{0c} = b_0 \quad \forall c$ F (33, 1050)=45.70*** Reject H_0

*** indicates significance at 1%; * indicates significance at 10%.
Numbers in parentheses are t-statistic of the coefficients.
Dummy variables of ISIC 1520 and year 2000 are dropped to avoid perfect multicollinearity.

Table 4.2. Descriptive Statistics, 1993 and 2000: Mean and Standard Deviation of Global Productivity Distributions in Processed Food Industries

Industry and ISIC code	Mean of log-TFP		Annual growth rate (%)
	1993	2000	
1511 Processing/preserving of meat	7.687	7.739	0.7
	(0.85)	(0.90)	
1512 Processing/preserving of fish	7.759	7.848	1.3
	(0.65)	(0.76)	
1513 Processing/preserving of fruits and vegetables	7.767	7.778	0.2
	(0.85)	(0.81)	
1514 Vegetable and animal oils and fats	7.796	8.002	2.9
	(0.82)	(0.94)	
1520 Dairy products	8.015	8.101	1.2
	(0.90)	(0.78)	

Numbers in parentheses are standard deviation.

Table 4.3. Effects on Productivity Distribution

	Dependent Variable					
	Mean	10^{th} Percentile	25^{th} Percentile	50^{th} Percentile (Median)	75^{th} Percentile	90^{th} Percentile
Industry- and Time-Fixed Effects						
Intercept	-3.557	-10.567	-9.095	-2.825	0.942	4.803
	(-1.00)	(-1.03)	(-1.58)	(-0.94)	(0.33)	(0.96)
Log of trade value	0.465***	0.715*	0.674***	0.439***	0.300**	0.155
	(3.17)	(1.68)	(2.83)	(3.53)	(2.53)	(0.75)
F test for industry-fixed effect	F(4, 27) = 38.39***	F(4, 27) = 6.86***	F(4, 27) = 13.64***	F(4, 27) = 46.96***	F(4, 27) = 64.31***	F(4, 27) = 20.74***
F test for time-fixed effect	F(7, 27) = 2.14*	F(7, 27) = 0.84	F(7, 27) = 1.60	F(7, 27) = 3.81***	F(7, 27) = 3.58***	F(7, 27) = 3.60***
R square	0.913	0.581	0.744	0.923	0.955	0.908
N = 40						
Industry- and Time-Random Effects						
Intercept	4.578***	3.103	3.955*	6.142***	6.780***	9.148***
	(2.73)	(1.15)	(1.89)	(3.55)	(4.13)	(3.72)
Log of trade value	0.139**	0.156	0.145	0.076	0.069	-0.012
	(1.99)	(1.39)	(1.66)	(1.06)	(1.01)	(-0.12)
Hausman test	$\chi^2(1)$ = 6.40**	$\chi^2(1)$ = 1.86	$\chi^2(1)$ = 5.69**	$\chi^2(1)$ = 12.84***	$\chi^2(1)$ = 5.72**	$\chi^2(1)$ = 0.86
N=40						
Industry-Fixed Effects						
Intercept	29.712***	59.451*	62.000***	46.910***	14.463	-35.968*
	(2.30)	(1.77)	(3.37)	(4.24)	(1.18)	(-1.74)
Log of trade value	0.355***	0.704***	0.633***	0.302***	0.147	0.014
	(3.76)	(2.87)	(4.70)	(3.73)	(1.64)	(0.09)

Table 4.3. (Continued)

	Dependent Variable					
	Mean	10th Percentile	25th Percentile	50th Percentile (Median)	75th Percentile	90th Percentile
Time trend	-0.015**	-0.035*	-0.035***	-0.023***	-0.005	0.022*
	(-2.08)	(-1.83)	(3.34)	(-3.68)	(-0.70)	(1.88)
F test for industry-fixed effect	F(4, 33) = 38.16***	F(4, 33) = 9.09***	F(4, 33) = 20.03***	F(4, 33) = 44.08***	F(4, 33) = 43.02***	F(4, 33) = 14.88***
R square	0.880	0.536	0.729	0.891	0.915	0.840
N=40						
Industry-Random Effects						
Intercept	12.90	7.324	28.151	33.831***	2.878	-55.056***
	(0.97)	(0.26)	(1.54)	(2.99)	(0.24)	(-3.10)
Log of trade value	0.190**	0.202	0.305**	0.173**	0.033	-0.171
	(2.14)	(1.28)	(2.64)	(2.26)	(0.41)	(-1.58)
Time trend	-0.005	-0.003	-0.014	-0.015**	0.002	0.034***
	(-0.64)	(-0.17)	(-1.39)	(-2.37)	(0.35)	(3.49)
Hausman test	$\chi^2(2)$ = 26.27***	$\chi^2(2)$ = 7.16**	$\chi^2(2)$ = 22.66***	$\chi^2(2)$ = 25.94***	$\chi^2(2)$ = 9.48***	$\chi^2(2)$ = 3.07
N=40						

*** indicates significance at 1%; ** indicates significance at 5%; * indicates significance at 10%.
Numbers in parentheses are t-statistic of the coefficients.

Table 4.4. Reallocation of Market Shares and Resources

	Dependent Variable			
	Annual growth rate of global value-added share	Annual growth rate of global output share	Annual growth rate of global labor share	Annual growth rate of global capital share
Time-Fixed Effect				
Annual growth rate of productivity relative to the industry average	1.112*** (43.74)	0.606*** (17.78)	0.173*** (6.19)	-0.038 (-1.16)
F test for time-fixed effect	F(4, 616) = 11.49***	F(4, 608) = 9.43***	F(4, 616) = 12.97***	F(4, 616) = 16.98***
R square	0.762	0.367	0.130	0.111
N	622	614	622	622
Time-Random Effect				
Intercept	-0.039 (-0.94)	-0.009 (-0.18)	-0.179 (-0.37)	-0.043 (-0.72)
Annual growth rate of productivity relative to the industry average	1.112*** (43.78)	0.606*** (17.79)	0.173*** (6.20)	-0.038 (-1.16)
Hausman test	$\chi^2(1) = 0$	$\chi^2(1) = 0.01$	$\chi^2(1) = 0$	$\chi^2(1) = 0.03$
N	622	614	622	622

Table 4.4. (Continued)

	Dependent Variable			
	Annual growth rate of global value-added share	Annual growth rate of global output share	Annual growth rate of global labor share	Annual growth rate of global capital share
Time-Trend				
Intercept	-5.215 (-0.55)	6.946 (0.55)	-17.637* (-1.69)	-33.674*** (-2.71)
Annual growth rate of productivity relative to the industry average	1.112*** (42.31)	0.605*** (12.27)	0.173*** (5.98)	-0.036 (-1.06)
Time trend	0.003 (0.54)	-0.003 (-0.55)	0.009* (1.69)	0.017*** (2.71)
R square	0.743	0.329	0.059	0.013
N	622	614	622	622

*** indicates significance at 1%; * indicates significance at 10%.
Numbers in parentheses are t-statistic of the coefficients.

Table 4.5. Decomposition of Global Market Share and Resource Reallocation

	Annual growth rate of global value-added share (%)	Annual growth rate of global output share (%)	Annual growth rate of global labor share (%)	Annual growth rate of global capital share (%)
Developed Countries	-10.76	-7.02	-5.54	-7.12
TFP Effect	-3.66	-1.99	-0.57	0.12
Among which:				
Trade Effect	-3.85	-2.10	-0.60	0.13
Non_TFP Effect	-7.10	-5.03	-4.97	-7.24
Developing Countries	2.30	3.86	1.30	-1.86
TFP Effect	3.84	2.09	0.60	-0.12
Among which:				
Trade Effect	-3.85	-2.10	-0.60	0.13
Non_TFP Effect	-1.54	1.77	0.70	-1.74

Decomposition is based on industry- and time-fixed-effect estimates of equation (4.2) and time-fixed-effect estimates of equation (4.4).
The average annual growth rate of $PRODIFF_{ijt}$ is 3.45% for developing countries, and -3.30% for developed countries.

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CHAPTER 5

SUMMARY AND CONCLUSIONS

The three essays of this dissertation investigated the trade and technology relationship, which is a key determinant of economic growth and well-being of both high- and low-income economies. Chapter 2 employed a monopolistic competition framework to derive the economic consequences of the productivity convergence between a technological leader and follower. In particular, convergence's effects on each country's relative wages, share of global markets, and welfare were derived. The analytical results showed that productivity convergence between a technological leader and follower enhanced the latter's relative wage and global production share, but weakened the leader's. Nevertheless, the leader's welfare unambiguously improved as convergence lifted its terms of trade, while the follower's welfare depended on the relative strength of convergence's positive income and negative terms-of-trade effects.

Data from 17 food industries in 30 countries, 1993-2001, were assembled to test the analytical predictions of Chapter 2. We first estimated cross-country total factor productivity (TFP), our indicator of technology, for each food industry through a value-added equation, whose results indicated significant variation in TFP levels and growth rates across countries. We then identified technological convergence by regressing TFP growth rates on initial TFP levels (β convergence) in 13 of 17 food industries. Empirical tests of convergence's effects on relative wages, share of global markets, and welfare are consistent with our analytical results. Convergence increased followers' global production shares and relative wages. Followers' welfare improved as convergence increased their real income, while that of the leaders also experienced gains from favorable terms of trade.

Chapter 3 examined the welfare effects of technological convergence, as in the monopolistic-competition model of Chapter 2, in international manufacturing industries. For this purpose, we used time-series data on 35 countries (11 developed and 24 developing) in 128 ISIC 4-digit manufacturing industries. As in Chapter 2, TFP estimates through a value-added equation showed cross-country variation in productivity level and growth rate in each manufacturing industry. Evidence of technological convergence was statistically significant in 16 of 28 and 18 of 100 industries during 1993-2001 and 1997-2001, respectively. Again, estimated convergence's effects on welfare were consistent with our analytical results. Convergence raised the follower's relative wage and global production share. All else constant, the follower's gains in global competitiveness came at the expense of the leader. However, convergence did not significantly affect either the leader's or follower's terms-of-trade in manufacturing industries. Thus, convergence enhanced the follower's welfare by improving its real income. Leader's welfare was unaffected by the convergence process.

Technological convergence's effects in Chapters 2 and 3 have several policy implications. For instance, encouraging open trade policies and facilitating technological convergence would bring long-run benefits to both technological leaders and followers. Moreover, technological progress is essential to welfare-enhancement, suggesting expanding technology-improvement investments, such as those in R&D and in public facilities, would help improve national competitiveness and welfare. However, public policies should pay attention to the consequent, intra-country redistribution of income favoring producers and consumers in low- and high-income economies, respectively.

Chapter 4 focused on the effects of trade liberalization on global productivity distribution and the cross-country resource reallocation in processed food industries. Here, we extended the new firm-heterogeneity trade models to a cross-country setting. We assembled data from 34 countries during 1993-2000 to empirically test the impacts of trade liberalization on the productivity and spatial distribution of 5 processed food industries. As in Chapter 1, we estimated cross-country and -industry productivity through a value-added equation. For each food industry, the global productivity distribution in every time period was approximated through non-parametric kernel density estimation. We then quantified the effects of trade liberalization on global productivity distribution by examining the evolution of alternative quantiles, e.g., mean, median. Our results showed that the mean and other quantiles of the global productivity distribution shifted to the right following trade liberalization. We concluded that multilateral trade liberalization increased an industry's (global) average productivity by forcing its least productive constituents to exit. In addition, countries with productivity growth faster than the global average acquired a larger share of global markets and resources. Chapter 4 demonstrated the important role of a liberalized trade in improving an industry's average productivity, and thus, the income and welfare of an economy. Therefore, policies facilitating productivity growth are beneficial to national competitiveness, but more attention is needed on the location and exit consequences of low-productivity constituents of an industry.

The three essays jointly highlight the important influence of global integration and technological convergence on nations' economic growth and well-being. However, policies promoting integration and convergence should pay attention to the consequent intra-country redistribution of income between producers and consumers.

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APPENDICES

Appendix I. Proof of Results 1-4

Result 1. Proof: Technological convergence lifts the follower's global production share

$(\frac{n^* x^*}{nx + n^* x^*})$:

(I.1) $$(\widehat{\frac{n^* x^*}{nx + n^* x^*}}) = -\frac{nx}{nx + n^* x^*}(\widehat{\frac{nx}{n^* x^*}}) = -\frac{L\beta^*}{L\beta^* + L^*\beta}(\widehat{\frac{\beta^*}{\beta}}) > 0,$$

where the hat indicates the proportional change in the corresponding variable (e.g.,

$\frac{n^* x^*}{nx + n^* x^*}$).

Result 2. Proof: Technological convergence reduces the leader's relative wage (w/w^*).

The relative wage is derived from the ratio of the two countries' equilibrium prices:

(I.2) $$(\widehat{\frac{w}{w^*}}) == (\widehat{\frac{p}{p^*}}) + (\widehat{\frac{\beta^*}{\beta}}) = (\theta - 1)(\widehat{\frac{x}{x^*}}) + (\widehat{\frac{\beta^*}{\beta}}) = -\theta(\widehat{\frac{\beta}{\beta^*}}) < 0.$$

Result 3. Proof: Technological convergence raises the leader's imported share of

consumption,

(I.3) $$(\widehat{\frac{TR}{wL}}) = \frac{1}{1+m}(\widehat{\frac{w^*}{w}}) = -\frac{\theta}{1+m}(\widehat{\frac{\beta^*}{\beta}}) > 0,$$

but reduces that of the follower,

(I.4) $$(\widehat{\frac{TR}{w^* L^*}}) = \frac{m}{1+m}(\widehat{\frac{w}{w^*}}) = \frac{m\theta}{1+m}(\widehat{\frac{\beta^*}{\beta}}) < 0,$$

where $m = \frac{w^* L^*}{wL}$ is the ratio of country *B*'s to country *A*'s national income.

Result 4. Proof: The indirect utility of the leader's representative consumer is

(I.5) $$V(w,p,p^*) = w^{\theta}(np^{\theta/(\theta-1)} + n^* p^{*\theta/(\theta-1)})^{1-\theta} = (\frac{w}{p})^{\theta}[n + n^*(\frac{p}{p^*})^{\theta/(1-\theta)}]^{1-\theta}.$$

Technological convergence unambiguously improves the consumer's welfare by lifting the terms of trade:

(I.6) $$\widehat{V} = \frac{m\theta}{1+m}(\widehat{\frac{p}{p^*}}) = \frac{m\theta(\theta-1)}{1+m}(\widehat{\frac{x}{x^*}}) = \frac{m\theta(\theta-1)}{1+m}(\widehat{\frac{\beta^*}{\beta}}) > 0.$$

Equilibrium indirect utility of the follower's representative consumer is

(I.7) $$V^*(w^*,p,p^*) = w^{*\theta}(np^{\theta/(\theta-1)} + n^* p^{*\theta/(\theta-1)})^{1-\theta} = (\frac{w^*}{p^*})^{\theta}[n^* + n(\frac{p^*}{p})^{\theta/(1-\theta)}]^{1-\theta}.$$

Technological convergence enhances the consumer's real income ($\widehat{\frac{w^*}{p^*}} > 0$), but diminishes the follower's terms of trade ($\widehat{\frac{p^*}{p}} < 0$). Under the assumption of exogenous β, the positive income effect dominates the negative terms-of-trade effect,

(I.8) $$\widehat{V^*} = \frac{-\theta(\theta+m)}{1+m}\widehat{\beta^*} > 0.$$

Therefore, technological convergence raises the follower's welfare as well.

Appendix II. Technological Convergence in a Specific-Factors Trade Model

An alternative to using the Krugman monopolistic competition framework for analyzing technological convergence is to employ an extension of the Ricardo-Viner-type specific-factors model (e.g., Jones and Scheinkman, 1977). In such a model, two countries (*A* and *B*) each produce two goods (i =1, 2) under perfect competition. Capital K_i is specific to the i^{th} sector, while labor L is perfectly mobile between the two sectors. Let Country *A*'s production function for the respective goods be:

(II.1) $$Q_1 = F(K_1, L_1, \psi_1)$$

$$Q_2 = G(K_2, L_2, \psi_2),$$

where Q_i and L_i are output and labor in the i^{th} sector (i =1, 2). Parameters ψ_1 and ψ_2 respectively denote product-augmenting technical change in Sectors 1 and 2. Corresponding variables and production functions in Country *B* are denoted with an asterisk. We assume Country *A* has the technological advantage in Sector 1 while Country *B* has the advantage in Sector 2, i.e. $\psi_1 > \psi_1^*$ and $\psi_2 < \psi_2^*$. Each production function is concave, strictly increasing, twice differentiable, and linearly homogeneous in *K* and *L*. Cost minimization, along with perfect labor mobility, implies the following factor price relationships:

(II.2) $$w = p_1 F_{L_1}(K_1, L_1, \psi_1) = p_2 G_{L_2}(K_2, L_2, \psi_2)$$

$$r_1 = p_1 F_{K_1}(K_1, L_1, \psi_1)$$

$$r_2 = p_2 G_{K_2}(K_2, L_2, \psi_2),$$

where p_i denotes price of the i^{th} good (i =1, 2), r_i is return to the i^{th} capital, w is the wage rate, and F_{L_1}, G_{L_2}, F_{K_1}, G_{K_2} respectively denote the marginal product of labor and specific capital in each sector. Given full factor employment, Country A exports Good 1 to, and imports Good 2 from, Country B. That is, *inter-industry* trade takes place.

Technological convergence occurs when ψ_1^* approaches ψ_1 and/or ψ_2 approaches ψ_2^*, following the respective approach functions $\psi_1^* = \psi_1(1-e^{-\lambda_1})$ and $\psi_2 = \psi_2^*(1-e^{-\lambda_2})$.

Result 1. In the presence of technological convergence, the return to the follower's specific capital rises, and the return to the leader's specific capital declines, in each sector. Wages in both countries rise, but the change in the relative wage depends upon the relative rates of convergence in the two sectors. A higher convergence rate in a country's lagging industry boosts its relative wage.

Result 2. In the presence of technological convergence, the two countries become more similar in their cross-sector labor allocations, i.e., $dL_1 - dL_1^* < 0$. In each sector, the follower's global production share rises and the leader's share falls.

Result 3. Changes in terms of trade depend upon the relative rates of convergence in the two sectors. Quicker convergence reduces relative product price in that sector, impairing the leader's terms of trade.

Similar to the monopolistic competition model, technological convergence in the specific-factors model increases the follower's relative factor returns and global production share. Terms-of-trade effects depend upon the two sectors' relative rates of technological convergence. Welfare effects require additional assumptions about those relative convergence rates. In particular, when convergence rates are equal across sectors, both countries' welfares improve because of rising incomes. When convergence rates instead differ across sectors, the country with the faster technological convergence in its lagging industry will gain on account of both rising incomes and rising terms-of-trade. The other country's net welfare change depends upon whether its rising income effect dominates its declining terms-of-trade effect. Hence, we continue to employ a monopolistically competitive framework in the body of this article, abstracting from factor substitution and utilization changes but maintaining scale economies, love of variety, and intra-industry trade.

Appendix III. Estimation of Cross-Country and –Industry TFP

For country *c* in industry *i* at time *t*, consider real value-added, y_{cit}, as a function of real capital stock k_{cit} and employment level l_{cit}:

(III.1) $$y_{cit} = Z_{cit} \cdot g_{cit}(k_{cit}, l_{cit}),$$

where Z_{cit} is an index of TFP (Hicks-neutral technological change). Assume that function $g_{cit}(k_{cit}, l_{cit})$ has a Cobb-Douglas form, so that an estimable form of equation (III.1) is

(III.2) $$\ln(y_{cit} / l_{cit}) = a_{0cit} + a_1 \ln(k_{cit} / l_{cit}) + \rho \ln l_{cit}$$

where $\rho = a_1 + a_2 - 1$. Equation (III.2) indicates that value added per worker is a function of capital per worker and total employment. The scale elasticity in equation (III.2) is given by $1+\rho$, where ρ indicates how far the value-added function deviates from constant returns to scale.

Since TFP generally varies across countries, industries, and time, the analysis of cross-country and –industry variation in value added per worker should allow for country-, industry-, and time-specific effects. The fixed-effect specification of equation (III.2) with country, industry, and time dummies is thus given by (Miller and Upadhyay 2002):

(III.3) $$\ln(y_{cit} / l_{cit}) = b_{0c} + b_{0i} + b_{0t} + a_1 \ln(k_{cit} / l_{cit}) + \rho \ln l_{cit} + \mu_{cit}$$

where b_{0c} is a country-specific intercept, b_{0i} is an industry-specific intercept, b_{0t} is a time-specific intercept, and μ_{cit} denotes a disturbance term. As a result, the logarithm of TFP of country *c* in industry *i* at period *t* is given as

$$\text{(III.4)} \qquad \ln TFP_{cit} = \ln(y_{cit}/l_{cit}) - \widehat{a_1}\ln(k_{cit}/l_{cit}) - \widehat{\rho}\ln l_{cit}\,.$$