Welfare Effects of Technological Convergence in the Food Industries

Jun Ruan, Munisamy Gopinath, and Steven Buccola

Department of Agricultural and Resource Economics
213 Ballard Extension Hall
Oregon State University
Corvallis, OR 97331-3601

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Extensive efforts have been made to understand the relationship between trade and technology (Grossman and Helpman, 1994). Traditional trade models treat technology as exogenous and address how changes in technology affect trade pattern and welfare. Recent research including new growth models have endogenized technology, which allows an examination of how trade affects the evolution of technology (Romer, 1990; Grossman and Helpman, 1991). Analytical studies show that international trade and capital flows serve as channels of international technological transfers.[1] That process, often referred to as technological convergence, enables countries to acquire advances in knowledge embedded in imported goods and capital inflows. Empirical work also has confirmed the significant contribution of trade and capital flows to technological convergence (Coe and Helpman, 1995; Coe, Helpman, and Hoffmaister, 1997; Aitken, Hanson, and Harrison, 1997; Lichtenberg and Van Pottelsberghe, 1998; Keller, 2001). However, few studies have addressed the consequences of technological convergence for trade. In particular, the role and significance of technological convergence in production and trade patterns, and the consequent welfare of technological leaders and followers, have received limited attention. In the present study, we analyze technological convergence and its consequences for processed food industries.

Processed food represents a growing share of foreign trade. Two-thirds of globally traded agricultural products, valued over $500 billion, undergo some form of value addition before shipment (Foreign Agricultural Trade of the United States, U.S. Department of Agriculture, 2005). Moreover, processed food industries have witnessed significant

[1] Since knowledge is considered to be a nonrival good, its partial nonexcludability facilitates technological spillovers across countries depending on the volume of trade (Grossman and Helpman, 1991).

multinational activity in the form of foreign direct investment (FDI), joint ventures, and licensing (International Direct Investment Statistics Yearbook, Organisation for Economic Co-operation and Development, 2004). The value of FDI, inward and outward, in the processed food sectors has more than tripled in the past few decades. Studies of trade and FDI patterns have shown that technology is a key source of comparative advantage in the processed food industries, but that its level and growth rate exhibit significant cross-country variation (Trefler, 1993; Bernard and Jones, 1996a; Harrigan, 1997; Chan-Kang, Buccola, and Kerkvliet, 1999; Morrison Paul, 2000). Relative to other manufacturing industries, evidence of quick technological convergence in processed food is consistent with its growing trade volume and FDI activity (Bernard and Jones, 1996a; Gopinath, 2003). However, the impact of technological convergence on production and trade patterns, and the welfare of countries with advanced and less-advanced technologies, i.e., leaders and followers respectively, have received limited attention.

In our study, we extend Krugman's (1980) monopolistic competition model to allow for technological differences between two countries in the form of variations in fixed and marginal production costs. Technological convergence is reflected in a narrowing inter-country gap between fixed or marginal production costs. Comparative static analysis indicates that technological convergence raises the follower's relative wage and global production share. The leader's welfare unambiguously increases as technological convergence lifts its terms of trade, even in the absence of further technological progress. However, the follower's welfare depends on the relative strength of its enhanced technology and the decline in its terms-of-trade.

The few analytical studies available on the impacts of technological convergence have shown mixed results regarding the gains and losses to leaders and followers (Baumol, Nelson, and Wolff, 1994). For instance, Krugman's (1990) technology-gap model suggests that the follower's catch-up will raise its real wage, but the leader's welfare may decline on account of terms-of-trade effects. Samuelson (2004) argues that if a less-developed country improves its exporting sector's technology, all countries would benefit from the increase in global output. However, if globalization improved a less-developed country's technology in a good exported by the advanced country, the latter would lose due to falling terms of trade. Bhagwati et al. (2004) counter Samuelson's (2004) assertions by claiming that losses due to declining terms of trade will become less relevant when the gains from trade induced by factor endowment differences are increasingly replaced by gains from intra-industry trade. Our own study on the welfare effects of technological convergence provides theoretical and empirical evidence of the gains from intra-industry trade.

Data in our study cover 30 countries, including 10 developed and 20 developing economies, in 17 processed food industries based on ISIC (Revision 3) 4-digit classifications over the period of 1993 to 2001. We implement a value-added function, allowing for country-, industry-, and time-specific effects to estimate empirical counterparts of technological levels and rates of change, i.e., total factor productivity (TFP) levels and growth rates, assuming variable returns-to-scale (Harrigan, 1999). Technological or productivity convergence is identified through a regression of TFP growth rates on initial levels (β convergence) in each processed food industry (Bernard and Jones, 1996a). For the industries with evidence of productivity convergence, we then estimate the welfare impacts of technological convergence, including the effects on the follower's relative wage and share in global value added. To our knowledge, this is the first study of cross-country TFP variations, convergences, and their effects at the 4-digit-level food industry level, providing depth to the convergence literature.

Conceptual Framework

In this section, Krugman's (1980) monopolistic competition model is extended by allowing for technological differences between two (groups of) countries to analyze the role of technological convergence in production and trade.

Trade Between Countries with Different Technologies

Each of the two countries, A and B, produces a series of potential goods in an industry under monopolistic competition. Production uses only one factor – labor. Unlike Krugman's (1980) model, country A here has a technological advantage over country B, reflected by differences in labor requirements of production. That is, the unit labor requirement of country A: $l_i = \alpha + \beta x_i$ is less than that of country B: $l_i^* = \alpha^* + \beta^* x_i^*$, because $\alpha < \alpha^*, \beta < \beta^*$, where α (α^*) and β (β^*) denote the fixed and marginal production cost of country A (B), respectively, and l_i (l_i^*) denotes the labor required for producing x_i (x_i^*) units of the *i-th* good in country A (B). Under free trade, consumers in either country consume all varieties produced by both countries. In this version of our technological-convergence model, transport costs are assumed to be zero.

The representative consumer in country A maximizes his utility, which takes constant elasticity of substitution (CES) form, $U = \sum_{i=1}^{n+n^*} C_i^\theta$ ($0 < \theta < 1$), subject to a budget constraint: $\sum_{i=1}^{n+n^*} P_i C_i = w$. Utility maximization yields the optimal consumption of the *i*-th good:

(1) $$C_i = \frac{w P_i^{1/(\theta-1)}}{\sum_{i=1}^{n+n^*} P_i^{\theta/(\theta-1)}},$$

where w denotes country A's wage rate, and P_i denotes the price of the *i*-th good.

Due to monopolistic competition, each good is produced by only one firm, and each firm produces only one good. Therefore, the i-th firm's profit is given as:

(2) $$P_i(x_i)x_i - (\alpha + \beta x_i)w ,$$

where x_i denotes the output of the i-th good. Profit maximization requires:

(3) $$P_i' x_i + P_i = \beta w ,$$

where $P_i' = \partial P_i / \partial x_i$, the derivative of the i-th price with respect to its output. In the long run, free entry brings profit to zero for each firm [setting equation (2) to zero].

In equilibrium, supply equals demand:

(4) $$x_i = LC_i + L^* C_i^* , \qquad i = 1,...,n ,$$

(4') $$x_i^* = LC_i + L^* C_i^* , \qquad i = n+1,...,n+n^* ,$$

where L is the labor force of country A, and the asterisk denotes the corresponding variable in country B. Labor markets in each country also clear, where total labor supply equals the total labor requirement for producing all goods:

(5) $$L = \sum_{i=1}^{n} (\alpha + \beta x_i) ,$$

(5') $$L^* = \sum_{i=n+1}^{n+n^*} (\alpha^* + \beta^* x_i^*) .$$

We follow the assumption of Krugman's (1980) model that a large number of goods is produced (but is still less than the number of potential goods), so that the pricing decision of any one firm will have a negligible effect on the marginal utility of income. In that case, each firm of either country faces a demand curve with a constant elasticity of $1/(1-\theta)$, which, given equation (3), yields the equilibrium price of the i-th good produced by either country:

(6) $$P_i = \beta w \theta^{-1} ,$$

$$(6') \qquad P_i^* = \beta^* w^* \theta^{-1}.$$

As β, w, θ are common in country A, all goods produced by country A have the same prices, denoted by P, i.e., $P_1 = ... = P_n = P = \beta w \theta^{-1}$. Similarly, the prices of good $n+1$ to good $n+n^*$ in country B are also identical, denoted by P^*, and $P^* = \beta^* w^* \theta^{-1}$.

From equation (1), we conclude that for either country, the representative individual consumes an equal amount of each domestically produced good and an equal amount of each imported good:

$$(7) \qquad C_a = \frac{wP^{1/(\theta-1)}}{nP^{\theta/(\theta-1)} + n^* P^{*\theta/(\theta-1)}}, \qquad C_b = \frac{wP^{*1/(\theta-1)}}{nP^{\theta/(\theta-1)} + n^* P^{*\theta/(\theta-1)}},$$

$$(7') \qquad C_a^* = \frac{w^* P^{1/(\theta-1)}}{nP^{\theta/(\theta-1)} + n^* P^{*\theta/(\theta-1)}}, \qquad C_b^* = \frac{w^* P^{*1/(\theta-1)}}{nP^{\theta/(\theta-1)} + n^* P^{*\theta/(\theta-1)}},$$

where C_a and C_b denote country A's individual consumption of each domestically produced good $(i = 1,...,n)$ and each imported good $(i = n+1,...,n+n^*)$, respectively; and C_a^* and C_b^* denote country B's individual consumption of each imported good $(i = 1,...,n)$ and each domestically produced good $(i = n+1,...,n+n^*)$, respectively.

The zero profit condition generates the equilibrium output of each good:

$$(8) \qquad x_i = \frac{\alpha}{(P_i / w - \beta)} = \frac{\alpha\theta}{\beta(1-\theta)}, \qquad i = 1,...,n$$

$$(8') \qquad x_i^* = \frac{\alpha^*}{(P_i^* / w^* - \beta^*)} = \frac{\alpha^*\theta}{\beta^*(1-\theta)}, \qquad i = n+1,...,n+n*$$

Equations (8) and (8') indicate that goods produced within a country have identical output, which is determined by the country's fixed and marginal costs. We define the output of each country A's good as x, and the output of each country B's good as x^*. Moreover, equation (4), (4'), (6), (6'), (7), and (7') yield the relationship between equilibrium good prices and outputs:

(9) $$\frac{P}{P^*} = (\frac{x}{x^*})^{\theta-1}.$$

Given the labor market-clearing conditions, the equilibrium number of varieties for each country are:

(10) $$n = \frac{L(1-\theta)}{\alpha},$$

(10') $$n^* = \frac{L^*(1-\theta)}{\alpha^*}.$$

The number of varieties in either country is determined by country size (L or L^*), fixed cost (α or α^*) and the degree of substitutability, θ. Country size affects the number of varieties positively, while fixed cost has a negative effect on it.

Country A's national income spent on imported goods (country B's exports), $n^*P^*LC_b$, is:

(11) $$n^*P^*LC_b = wL\frac{n^*P^{*\theta/(\theta-1)}}{nP^{\theta/(\theta-1)} + n^*P^{*\theta/(\theta-1)}} = \frac{wLw^*L^*}{wL + w^*L^*},$$

Likewise, country A's exports (country B's imports), $nPL^*C_a^*$, is given by:

(11') $$nPL^*C_a^* = w^*L^*\frac{nP^{\theta/(\theta-1)}}{nP^{\theta/(\theta-1)} + n^*P^{*\theta/(\theta-1)}} = \frac{wLw^*L^*}{wL + w^*L^*}.$$

Equations (11) and (11') show that country A's imports equal its exports so that the trade balance is zero. In the following, we will denote exports or imports of either country as *TR*, i.e., trade.

Technological Convergence

As labor is the only factor of production, convergence in this model is based on labor productivity (x/l and x^*/l^*). Technological convergence is reflected in a narrowing inter-country fixed or marginal cost of production, i.e., the decline of α^*/α and/or β^*/β. The focus here is on a convergence of marginal costs, holding fixed costs constant.[2]

Now suppose that β^* approaches β as follows:

(12) $$\beta^* = \beta/(1 - e^{-\lambda I}),$$

where I denotes the interaction between the two economies, and λ denotes the rate of technological convergence in marginal costs. The leader (country A)'s marginal cost (β) is given, while that of the follower (country B)'s (β^*) is endogenous in equation (12).

Comparative statics on equation (12) suggests that the faster is the rate of technological convergence, the greater is the productivity in "catch-up" countries, that is, the lower is the marginal cost of the follower:

(13) $$\frac{\partial \beta^*}{\partial \lambda} = -\beta I e^{-\lambda I}(1 - e^{-\lambda I})^{-2} < 0 .$$

Output: The output of each variety is determined by the country's fixed and marginal costs. When technology converges, the leader's output will not change due to its constant fixed and marginal costs. But the follower's output of each variety will increase with the decline in its marginal cost. As a result, the follower's relative supply in the world market goes up, and global supply also rises.

Terms of Trade: From equation (9), a country's terms of trade is negatively correlated with its relative output of each variety. The expansion of the follower's output reduces its terms of trade (P^*/P), but raises that of the leader.

Relative Wage: Country A's relative wage with respect to country B is given as w/w^*, which in equilibrium is determined by two countries' marginal costs (β and β^*), and the relative good price (P/P^*). From equations (6) and (6'),

[2] The assumption of constant fixed costs is reasonable if we assume the fixed costs are set-up so that technological progress only affects the marginal costs.

(14) $$\frac{w}{w^*} = (\frac{P}{P^*})\frac{\beta^*}{\beta}.$$

From equation (9), the relative wage is determined by both countries' fixed and marginal costs as well as the value of θ:

(14') $$\frac{w}{w^*} = (\frac{P}{P^*})\frac{\beta^*}{\beta} = (\frac{x}{x^*})^{\theta-1}\frac{\beta^*}{\beta} = (\frac{\alpha}{\alpha^*})^{\theta-1}(\frac{\beta}{\beta^*})^{-\theta}.$$

Since $\alpha < \alpha^*, \beta < \beta^*$, $0 < \theta < 1$, the leader's relative wage is greater than unity, i.e., $(w / w^*) > 1$. In other words, workers in the leading country enjoy a higher wage rate.

Proposition 1. *Relative wage between two countries is directly proportional to relative productivity levels. Technological convergence will lead to factor price equalization.*

Proof: As technology converges, the follower's relative marginal cost declines, leading to an increase in its relative wage rate:

(14'') $$\widehat{\frac{w}{w^*}} = \theta(\widehat{\frac{\beta^*}{\beta}}) < 0,$$

where the hat indicates the proportional change of the corresponding variable (e.g., w / w^*). In this setting, inter-country wage differences result from a technological gap, and technological convergence will thus shrink the wage gap across countries. If the countries' technological levels continue converging until they become identical, they will eventually reach the same wage level, i.e., factor price equalization.[3]

Proposition 2. *Technological convergence will increase (decrease) the leader's (follower's) imported share of consumption.*

[3] Note that complete factor price equalization requires convergence in both fixed cost and marginal cost. However, convergence in marginal cost itself will reduce two countries' technological gap and their wage gap.

Proof: Country A's imported share of consumption is given by TR/wL, the share of trade in its national income:

(15) $$\frac{TR}{wL} = \frac{n^* P^{*\theta/(\theta-1)}}{nP^{\theta/(\theta-1)} + n^* P^{*\theta/(\theta-1)}} = \frac{w^* L^*}{wL + w^* L^*}.$$

Its proportional change is,

(15') $$\frac{\widehat{TR}}{wL} = \frac{\widehat{w^*} - \widehat{w}}{1+m} > 0,$$

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

The leader allocates its national income between the demand for domestic goods and that for imported goods. Technological convergence boosts the follower's output of each variety, and reduces its relative price, thereby leading to an increase in the leader's relative demand for the follower's products. Note that technological convergence causes an increase in the elasticity of production scale by reducing the follower's marginal cost ($\frac{\partial \ln x^*}{\partial \ln l^*} = 1 + \frac{\alpha^*}{\beta^* x^*}$) and, thus, an increase in the follower's output of each variety. With technological convergence, trade arises not only from consumers' love-of-variety preference as in Krugman (1980), but also from scale economies and the resulting change in global output composition. In contrast, country B's imported share of consumption ($TR/(w^* L^*)$) declines in response to technological convergence:

(16) $$\frac{\widehat{TR}}{w^* L^*} = \frac{m(\widehat{w} - \widehat{w^*})}{1+m} < 0.$$

Welfare: Due to the long-run zero profit condition, a country's national welfare is based on changes in consumers' utility. We assume during the process of technological convergence that total labor force in both countries (L and L^*) is fixed, so that the change in a country's welfare is fully captured by the change in its representative individual utility. In equilibrium, the indirect utility of country A's representative individual is:

$$(17) \qquad V(w, P, P^*) = w^{\theta}(nP^{\theta/(\theta-1)} + n^* P^{*\theta/(\theta-1)})^{1-\theta} = (\frac{w}{P})^{\theta}[n + n^*(\frac{P^*}{P})^{\theta/(\theta-1)}]^{1-\theta}.$$

Proposition 3. *Technological convergence will benefit the leading country by increasing its terms of trade, but its effect on the follower's welfare depends on the relative strength of the follower's enhanced technological level and the negative terms-of-trade effects.*

Proof: As indicated in equation (17), the change in country A's individual utility is determined by changes in individual real income (w/P), country A's terms of trade (P/P^*), and the numbers of varieties in two countries (n and n^*).

$$(17') \qquad \hat{V} = \theta(\widehat{\frac{w}{P}}) + \frac{m\theta}{1+m}(\widehat{\frac{P}{P^*}}) + \frac{1-\theta}{1+m}(\hat{n} + m\widehat{n^*}).$$

Exogeneity of β suggests constant real income of country A, and the assumption of constant fixed costs implies the constant numbers of varieties in both countries. Therefore, the change in country A's individual utility ($\hat{V}$) only results from the change in its terms of trade:

$$(17'') \qquad \hat{V} = \frac{m\theta}{1+m}(\hat{P} - \widehat{P^*}) > 0.$$

As indicated above, the leader's terms of trade goes up as technology converges; therefore, technological convergence improves country A's welfare.

The equilibrium indirect utility of country B's representative individual is:

$$(18) \qquad V^*(w^*, P, P^*) = w^{*\theta}(nP^{\theta/(\theta-1)} + n^* P^{*\theta/(\theta-1)})^{1-\theta} = (\frac{w^*}{P^*})^{\theta}[n^* + n(\frac{P}{P^*})^{\theta/(\theta-1)}]^{1-\theta}.$$

Due to the constant numbers of varieties, the change in country B's individual utility results from changes in individual real income and country B's terms of trade:

(18') $$\widehat{V^*} = \theta(\widehat{\frac{w^*}{P^*}}) + \frac{\theta}{1+m}(\widehat{\frac{P^*}{P}}),$$

where the first term on the right hand side is the change in country B's individual real income and the second term on the right hand side indicates the change in country B's terms of trade. With technological convergence, country B is experiencing technological progress, leading to an increase in its real income ($(\widehat{\frac{w^*}{P^*}}) > 0$). If the positive income effect dominates the negative terms-of-trade effect, the second term on the right hand side of equation (18'), country B's welfare will finally improve. Under the assumption of exogenous β, equation (18') becomes:

(18") $$\widehat{V^*} = \frac{-\theta(\theta+m)}{1+m}\widehat{\beta^*} > 0,$$

That is, country B's welfare will improve when technology converges.

In sum, technological convergence has a positive net effect on both the leader's and the follower's welfare. Though the leader's share in global production declines, it enjoys higher terms of trade from the follower's catch-up. The follower also benefits from its own technological progress due to increases in its real income and share of global markets.

Empirical Framework for Technological Convergence

We represent technology by total factor productivity, as estimated econometrically from industry-specific value added function (Bernard and Jones, 1996a; Harrigan, 1999; Miller and Upadhyay, 2002). Details of TFP computation are presented in Appendix A. The econometric approach allows for a variable returns-to-scale technology and monopolistic competition.[4] The approach also permits testing hypotheses on robustness of cross-country measures of TFP.

[4] See Caves, Christensen and Diewert (1982), Harrigan (1997) and Ball *et al.* (2001) for an index number approach to measure TFP.

Moreover, the value-added specification is consistent with TFP convergence (or divergence) models (Miller and Upadhyay, 2002; Bernard and Jones 1996a; Baumol, Nelson, and Wolff, 1994; Ark and Pilat, 1993).

With industry- and country-specific data on TFP levels in time series, we can explicitly measure the follower's relative TFP with respect to the leader using their TFP ratios, and examine the industry-specific β-convergence by identifying the relationship between the followers' relative TFP growth rates and their initial relative TFP levels. More specifically,

(19) $$\Delta \ln(TFP_{ci}) = \delta_0 + \delta_i D_i \ln(TFP_{ci0}) + \mu_{ci},$$

where $\Delta \ln(TFP_{ci})$ denotes the average growth rate of country *c*'s productivity relative to the leader, country 1, in industry *i* over *T* periods; $\ln(TFP_{ci0})$ denotes country *c*'s relative TFP level in industry *i* at the base year; δ_i denotes the industry-specific slope of industry *i*; and D_i denotes the industry-specific dummy variables. Using the followers' TFP levels and growth rates relative to those of the leader will yield their "catch-up" speed toward the leader (Bernard and Jones, 1996a). A negative coefficient (δ_i) on log of the initial productivity level indicates the growth rates of countries' TFP are negatively correlated with their initial TFP levels, suggesting productivity convergence among countries. Given the sample length *T*, the speed or rate of productivity convergence of industry *i*, λ_i, can be calculated using the coefficient, δ_i:

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

When $\lambda_i > 0$, provides an impetus for "catch-up" toward the leader: productivity differentials between two countries increase the relative growth rate of the country with lower productivity (Bernard and Jones, 1996a). Therefore, $\delta_i D_i \ln(TFP_{ci0})$ in equation (20) captures the portion of the followers' TFP growth rates that are induced by their technological "catch-up", while TFP growth caused by factors other than convergence can be measured by $\delta_0 + \mu_{ci}$.

Empirical Specification of Welfare Effects

Decomposition of the followers' TFP growth enables us to examine hypotheses on the effects of convergence on wage, production, and national welfare. Proposition 1 shows that the wage gap between the leader and the follower is negatively affected by convergence. Therefore, the effect of convergence on the follower's relative wage is estimated controlling for factor accumulation as:

(21) $$\Delta Wage_{ci} = \gamma_1 \Delta TC_{ci} + \gamma_2 \Delta TN_{ci} + \gamma_3 \Delta Cap_{ci} + \gamma_4 \Delta Edu_c$$

where $\Delta Wage_{ci}$ denotes the average growth rate of country *c*'s relative wage in industry *i* over *T* periods; ΔTC_{ci} ($\delta_i D_i \ln(TFP_{ci0})$) and ΔTN_{ci} ($\delta_0 + \mu_{ci}$) denote TFP growth of country *c* in industry *i* induced by convergence and other factors, respectively; and ΔCap_{ci} and ΔEdu_c denote the average growth rate of country *c*'s relative capital intensity in industry *i* and relative education level, respectively. We expect the estimates of γ_1 and γ_2 to be positive since faster TFP growth from convergence or otherwise will increase the follower' relative wage. Capital intensity positively affects the wage rate because marginal product of labor increases with the growth of capital-labor ratio. Moreover, when educational levels increase, they tend to raise relative wages, so that the coefficient on ΔEdu_c, γ_4, is expected to have a positive sign.

Controlling again for a country's relative factor accumulation, convergence raises the follower's production share in global markets but reduces that of the leader:

(22) $$\Delta S_{ci} = \varphi_1 \Delta TC_{ci} + \varphi_2 \Delta TN_{ci} + \varphi_3 KS_{ci} + \varphi_4 \Delta LS_{ci}$$

where ΔS_{ci} denotes the average growth rate of country *c*'s share in global value added in industry *i* over *T* periods; and ΔKS_{ci} and ΔLS_{ci} denote the average growth rate of country *c*'s global capital and labor share, respectively, in industry *i* over *T* periods. As before, we expect the estimates of φ_1 and φ_2 to be positive.

Recall that technological convergence has two opposite effects on the follower's national welfare: income (positive) and terms-of-trade (negative) effects. To isolate these two effects on welfare, we employ a two-stage estimation. The first stage is to separately estimate the impacts of convergence on the follower's income and on its relative price. From equation (21), the coefficient on ΔTC_{ci} ($\hat{\gamma}_1$) identifies the income effect of technological convergence. For the terms-of-trade effect, data on domestic and foreign prices are not available. However, we use the ratio of imports to domestic supply in national consumption, IR_{ci}, as a proxy of the country's relative price. Imports apply only to that from the leader and domestic supply in national consumption is defined as domestic output less exports to leader. Therefore, the terms-of-trade equation is specified as:

(23) $$\Delta IR_{ci} = \eta_1 \Delta TC_{ci} + \eta_2 \Delta TN_{ci}$$

where ΔIR_{ci} denotes the average growth rate of the ratio of imports to domestic supply in national consumption defined using trade with the leader. Since growth in the follower's relative TFP negatively affects its relative prices, we expect estimates of both η_1 and η_2 to be negative.

The second stage is to estimate the contribution of income and terms-of-trade effects to the changes in national welfare. Welfare is represented by domestic absorption, defined as the sum of domestic output and imports from the leader less exports to the leader:

(24) $$\Delta RY_{ci} = \phi_1 \Delta Wagefit_{ci} + \phi_2 \Delta IRfit_{ci}$$

where ΔRY_{ci} denotes the average growth rate of domestic absorption of country *c* in industry *i* over *T* periods; and $\Delta Wagefit_{ci}$ and $\Delta IRfit_{ci}$ are the respective fitted values of $\Delta Wage_{ci}$ and ΔIR_{ci} from equation (21) and (23), attributable to convergence. Increases in relative wage and terms-of-trade improve the follower's welfare, so we expect the estimates of ϕ_1 and ϕ_2 to be positive.

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, wages, and output. Data on 17 processed food industries, based on ISIC (revision 3) 4-digit classifications in 30 countries from 1993-2001, are taken from INDSTAT4 (table 2). 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). Some countries' data are only available in selected years, so we use their data classified at ISIC revision 2 to complete the series. Correspondence between ISIC revision 2 and revision 3 for U.S. industries is from U.S. Bureau of Census, and we assume this correspondence is applicable to all countries.[5] As data availability varies across countries and industries, we have an unbalanced data panel. Except that the employment data are expressed in

[5] Data for some countries are available in both revisions in particular years, which enables us to test the average difference between the data reported in revision 3 and those converted to revision 3 from revision 2 using U.S. industry correspondence. Results of t-tests indicate that none of data differences in value-added, employment, or gross fixed capital formation are significantly different from zero at 5% significance level, supporting our assumption that U.S. correspondence between two revisions can be applied to other countries.

units, other production data are measured in current local currencies in INDSTAT4. In order to make them internationally comparable, we fist convert cross-country and -industry data to constant 2000 local currencies by using their corresponding price index from 2005 World Development Indicators (WDI), World Bank, then convert them to constant 2000 U.S. dollars by using the purchasing power parity (PPP) conversion factors from 2005 WDI.[6]

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):

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

where I_t is the gross fixed capital formation in year *t*, K_t is the capital stock at the end of year *t*, and d is the depreciation rate. We follow Hall *et al*. (1988)'s procedure to solve the problem of missing base-year capital stock data:

$$K_{t_0} = \frac{I_{t_0}}{d+g}$$

where K_{t_0} is the initial capital stock, I_{t_0} is the investment in base year (t_0), and *g* is the presample growth rate of new capital per year. Country-specific presample capital growth rates are derived as the average annual growth rate of gross fixed capital formation in the aggregate economy over the 10-year pre-sample period. Data on annual gross-fixed-capital-formation growth rates are available in WDI. We set depreciation rate (d) at 8% per year. Finally, the number of students enrolled in secondary education is adopted as a proxy of the country's education level, whose data are taken from World Bank Education Statistics Database (EdStats).

[6] 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 of the aggregate economy; and consumer price index (CPI) of the aggregate economy is used to deflate wages.

Preliminary Results

Results on TFP estimation, equation (A.5), are presented in table 1. The coefficient on log of capital per unit of labor is significant at the 5% level, indicating that the capital elasticity of value added is 0.226. The statistically significant coefficient on log of employment (-0.045) suggests that food industries exhibit decreasing returns to scale, albeit marginally. Prior studies found mixed evidence on scale economy in food processing industries (Chan-Kang, Buccola, and Kerkvliet, 1999; Gopinath, 2003). For instance, Chan-Kang, Buccola, and Kerkvliet (1999) find modest scale economies in the U.S. food processing industry, while Gopinath (2003) finds significant scale diseconomy in that of 13 OECD countries, both of which are at the aggregate level. Moreover, our model is based on the "value-added" technology rather than the "gross output" technology, which excludes intermediates due to data limitations. The coefficient on log of capital per unit of labor and that on log of employment combine to generate an implied elasticity of value-added with respect to employment of 0.729. The latter result is consistent and indicates that processed food industries are labor intensive.

With the coefficients on log of capital per labor and log of employment, cross-country and -industry TFP are derived for each time period. An F-test rejects the null hypothesis of identical technology across countries [F(29,2972), 148.55] at the 1% level. Thus, TFP estimates show significant variation in levels and growth rates across countries, among which U.S. is the technological leader in 11 of 17 processed food industries.[7] Other leaders include Japan, Korea, Mexico, and Spain (Table 2). The result that U.S. TFP levels are relatively higher in most food industries is consistent with the findings of other studies (Harrigan, 1997; Chan-Kang, Buccola,

[7] Except ISIC 1542, U.S. production data are not available in time series in other five industries (ISIC 1532, ISIC 1541, ISIC 1543, ISIC 1544, ISIC 1549) where U.S. is not the technological leader.

and Kerkvliet, 1999; Gopinath, 2003). However, because our results are based on four-digit industries, the United States may not necessarily be the productivity leader in specific subsectors (e.g., sugar), although its average productivity across all subsectors is higher than that in other countries.

Table 3 reports the results of β-convergence test of equation (19). As indicated by convergence hypothesis, a negative coefficient on log of initial (relative) TFP level suggests productivity convergence. Among 17 food industries, 13 of them, i.e., ISIC 1511, ISIC 1512, ISIC 1513, ISIC 1520, ISIC 1531, ISIC 1533, ISIC 1541, ISIC 1543, ISIC 1549, ISIC 1551, ISIC 1552, ISIC 1553, ISIC 1554, have a negative coefficient on log of initial (relative) TFP level that is at least significant at the 10% level. That is, countries with relatively lower TFP levels tend to have a relatively higher TFP growth rate, which is evidence of their catch-up to the leader's productivity, i.e., productivity convergence. The convergence regressions explain about 22.5% of the variation in TFP growth rates, which is not surprising since TFP growth is explained by a number of other factors, including R&D, technological opportunity, and appropriability conditions. Given equation (20), we calculate rates of convergence for the thirteen industries with statistically significant evidence of productivity convergence. The rate of convergence varies between 2.5% and 9.5% per year. Findings of TFP convergence indicate the public-good nature of technology. In comparison, Bernard and Jones (1996a) find that the speed of TFP convergence among OECD countries in agriculture and manufacturing to be 6.50% and 1.68 % per year, respectively. Different convergence rates in the two studies have several implications. First, evidence of productivity convergence is stronger in recent years than before, and possible reasons include the development of information technology and the resulting deeper economic integration, i.e., globalization. Second, a higher speed of global productivity convergence than that among OECD countries may indicate developing countries are experiencing faster “catch-up” toward the technological leaders than developed countries are. This finding reflects to some extent the arguments of Bernard and Jones (1996b) that they expect TFP convergence among the countries that are adopting existing technology but no convergence among the innovators. Third, disaggregate food industries may exhibit stronger productivity convergence than the aggregate food industry does since “intra-industry” trade is accounting for an increasing share of global trade, which is accompanied by international technological transfers within industries.

Results on the wage effect of technological convergence are shown in table 4a, where coefficients on all the explanatory variables have the expected positive signs and are significant at the 5% level. An 1% increase in the follower’s TFP induced by technological convergence will boost its relative wage by 0.26%, indicating technological convergence raises the follower’s relative wage level, consistent with our theoretical prediction. The wage effect of TFP growth from other sources is slightly weaker, with an elasticity of 0.192. The elasticity of the follower’s relative wage with respect to its relative capital intensity is 0.214, indicating higher capital intensity increases the relative wage rate by raising the marginal product of labor. Among the explanatory variables, growth of countries’ relative education levels has the strongest impact on the growth of their relative wages with the coefficient of 0.298. The regression of equation (21) explains about 26.7% of the variation in growth rates of the followers’ relative wage.

Table 4b reports results of productivity convergence’s effect on the followers’ global value-added shares (equation, 22). Coefficients on all the explanatory variables are positive again, and significant at the 5% level, consistent with our expectations. Here, an 1% increase in the follower’s TFP from technological convergence will increase its global value-added share by

0.986%, suggesting the follower's share in global value added grows faster when technological convergence is stronger. The effect of TFP growth due to other factors is also significant, with an elasticity of 0.867. Variations in both global capital share and global labor share affect the growth in global value-added share positively. But the effect of capital growth is modest, with an elasticity of 0.235 while the effect of labor growth is more significant with an elasticity of 0.833. Effects of TFP growth from both technological convergence and non-convergence sources are greater than those of variations in capital share and labor share, suggesting TFP is relatively more important than factor accumulation in determining a country's competitiveness in global markets. Regression of equation (22) explains 92.5% of the variation in growth rates of the followers' global value-added shares. Both table 4a and 4b show the coefficient on TFP growth from technological convergence is greater than that on TFP growth due to other factors. This finding indicates that technological "catch-up" is a key determinant of the follower's global competitiveness, reflected by its relative wage and global production share.

In sum, regressions of wage effect and value-added effect suggest technological convergence increases the follower's relative wage and its global production share, which confirms our theoretical predictions that technological convergence will enhance the follower's competitiveness in the world market.[8]

Conclusions

In this study, we investigate the welfare effects of technological convergence in food industries. We extend Krugman's monopolistic competition model to allow for technological differences between two countries. Technological convergence is reflected in a narrowing inter-country gap between fixed or marginal production costs. Comparative static analysis indicates that

[8] Welfare equations (equation (23) and (24)) have not been estimated since trade data are unavailable at present.

technological convergence raises the competitiveness of the follower nation, as reflected in its share of global production, but weakens that of the leader. However, the leader's welfare rises as technological convergence raises its terms of trade. The follower's welfare depends on the relative strength of its enhanced technological level and the decline in its terms-of-trade gains.

Empirically, data on 30 developed and developing countries in 17 processed food industries are assembled to estimate cross-country and –industry TFP levels and rates of growth through a value-added equation. TFP estimates indicate significant variation in levels and growth rates of productivity across countries. Technological convergence is identified through a regression of relative TFP growth rates on initial relative TFP levels in each food industry. In thirteen out of seventeen food industries, we find evidence of technological convergence.

For the thirteen industries with technological convergence, we then decompose TFP growth into that from technological convergence and other factors. Welfare equations from the theoretical analysis guide specifications to estimate the effects of convergence on the followers' relative wages and global value-added shares. We find a statistically significant and positive relationship between followers' relative wages (shares in global value-added) and technological convergence. The latter confirms that technological convergence increases followers' welfare and competitiveness in global markets.

Our investigation of technological convergence and its welfare impacts contributes to the literature on dynamic comparative advantage. Policy implications for followers include maintaining open trade and foreign investment regimes, and encouraging R&D that would assist in catch-up with technological leaders. Implications for leaders include transferring some of its consumers' welfare gains into productivity-enhancing investments, ameliorating some of the strength of its original leadership loss.

Table 1. Estimates of the value-added equation: Dependent variable: log of value-added per worker, 1993-2001 (Fixed effect)

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	(dropped)	
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	(dropped)				
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)						
United States	10.045**	(48.06)						
R^2	0.998							
F test: H_0: $b_{0c} = b_0 \quad \forall c$			$F\ (29,2972)$=148.55**			Reject H_0		

** indicates significance at 5%.

Numbers in parentheses are t-statistic of the coefficients.

Table 2. Productivity leaders in 17 processed food industries

Industry and ISIC code	Productivity leader
1511 Processing/preserving of meat	United States
1512 Processing/preserving of fish	United States
1513 Processing/preserving of fruits and vegetables	United States
1514 Vegetable and animal oils and fats	United States
1520 Dairy products	United States
1531 Grain mill products	United States
1532 Starches and starch products	Spain
1533 Prepared animal feeds	United States
1541 Bakery products	Japan
1542 Sugar	Korea
1543 Cocoa, chocolate and sugar confectionery	Japan
1544 Macaroni, noodle and similar products	Korea
1549 Other food products n.e.c.	Mexico
1551 Distilling, rectifying and blending of spirits	United States
1552 Wines	United States
1553 Malt liquors and malt	United States
1554 Soft drinks; mineral waters	United States

Table 3. Test of productivity convergence: Dependent variable: average growth rate of productivity relative to the leader over 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**	0.058
	(-4.54)	
1512 Processing/preserving of fish	-0.032**	0.038
	(-2.19)	
1513 Processing/preserving of fruits and vegetables	-0.024**	0.026
	(-2.26)	
1514 Vegetable and animal oils and fats	-0.016	
	(-1.58)	
1520 Dairy products	-0.049**	0.062
	(-4.95)	
1531 Grain mill products	-0.023**	0.025
	(-3.07)	
1532 Starches and starch products	-0.082	
	(-1.42)	
1533 Prepared animal feeds	-0.045**	0.057
	(-4.24)	
1541 Bakery products	-0.055**	0.073
	(-3.37)	
1542 Sugar	-0.001	
	(-0.09)	
1543 Cocoa, chocolate and sugar confectionery	-0.066*	0.095
	(-1.76)	
1544 Macaroni, noodle and similar products	-0.026	
	(-0.74)	
1549 Other food products n.e.c.	-0.046**	0.046
	(-2.97)	
1551 Distilling, rectifying and blending of spirits	-0.038**	0.046
	(-3.78)	
1552 Wines	-0.044**	0.054
	(-3.97)	
1553 Malt liquors and malt	-0.048**	0.061
	(-3.81)	
1554 Soft drinks; mineral waters	-0.039**	0.047
	(-3.84)	
R^2	0.225	

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

Table 4. Effects of productivity convergence

4.a. Wage equation: Dependent Variable: average growth rate of wage rate relative to the leader over 1993-2001

Independent variable	Coefficient	*t-stat*
TFP growth rate induced by technological convergence	0.260**	4.48
TFP growth rate from non-convergence sources	0.192**	5.05
Average growth rate of relative capital intensity over 1993-2001	0.214**	6.82
Average growth rate of relative education level over 1993-2001	0.298**	2.68
R^2	0.267	

4.b. Value-added-share equation: Dependent Variable: average growth rate of global value-added share over 1993-2001

Independent variable	Coefficient	*t-stat*
TFP growth rate induced by technological convergence	0.986**	23.80
TFP growth rate from non-convergence sources	0.867**	33.07
Average growth rate of global capital share over 1993-2001	0.235**	10.27
Average growth rate of global labor share over 1993-2001	0.833**	29.24
R^2	0.925	

** indicates significance at 5%.

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Appendix A. Estimation of cross-country and –industry TFP levels in time series.

For country *c* in industry *i* at time *t*, consider real value-added, y_{cit}, as a function of the real capital stock, k_{cit}, and the level of employment, l_{cit}:[9]

(A.1) $$y_{cit} = f_{cit}(k_{cit}, l_{cit}).$$

Under the assumption of Hicks-neutral technological differences over time and across countries, the function in equation (A.1) can be rewritten as:

(A.2) $$y_{cit} = \mathrm{Z}_{cit} \cdot g_{cit}(k_{cit}, l_{cit})$$

where Z_{cit} is an index of TFP. Assume the function $g_{cit}(k_{cit}, l_{cit})$ has a Cobb-Douglas form, therefore, an estimable form of equation (A.2) will be:

(A.3) $$\ln y_{cit} = a_{0cit} + a_1 \ln k_{cit} + a_2 \ln l_{cit}$$

or, subtracting $\ln l_{cit}$ from both sides:

(A.4) $$\ln(y_{cit} / l_{cit}) = a_{0cit} + a_1 \ln(k_{cit} / l_{cit}) + \rho \ln l_{cit}$$

where $\rho = a_1 + a_2 - 1$. Equation (A.4) indicates that value added per worker is a function of capital per worker and total employment. The scale elasticity in equation (A.4) is given by $1+\rho$, where ρ measures how far the value-added function deviates from constant returns to scale.

Since TFP generally varies across countries and industries, and over time, the analysis of cross-country and –industry variation in value added per worker should allow for country-, industry-, and time-specific effects. Therefore, the fixed-effect specification of equation (A.4) with country, industry, and time dummies is given by (Miller and Upadhyay, 2002):

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[9] Recall in our theoretical model, a country's technological level is measured by its labor productivity (x / l or x^* / l^*) given the single factor of production – labor. However, technological level will be measured empirically using total factor productivity (based on inputs of both capital and labor) rather than labor productivity since labor productivity does not allow the identification of separate influences of technology and capital growth (Bernard and Jones, 1996b).

(A.5) $$\ln(y_{cit}/l_{cit}) = b_{0c} + b_{0i} + b_{0t} + a_1 \ln(k_{cit}/l_{cit}) + \rho \ln l_{cit} + \varepsilon_{cit}$$

where b_{0c} is a country-specific intercept, b_{0i} is an industry-specific intercept, and b_{0t} is a time-specific intercept. As a result, the logarithm of TFP of country *c* in industry *i* at period *t* is given as $\ln(y_{cit}/l_{cit}) - \widehat{a_1} \ln(k_{cit}/l_{cit}) - \widehat{\rho} \ln l_{cit}$.