Journal of Agricultural and Resource Economics 32(3):448–461

The Effect of Innovation on Agricultural and Agri-food Exports in OECD Countries

Pascal L. Ghazalian and W. Hartley Furtan

This paper investigates the effect of innovation on primary agricultural and processed food product exports among the Organization for Economic Cooperation and Development (OECD) countries. A theoretical gravity equation that accounts for innovation is derived. The empirical exercise uses panel data sets covering 21 OECD countries for the period 1990–2003. The R&D capital stock is employed as a tangible way of measuring innovation. Empirical results show that R&D has enhanced exports in the primary agricultural sector. Meanwhile, the market expansion effect of R&D appears to be more than offset by the market power effect in the food processing sector, resulting in a decrease in exports. Also, evidence was found of a positive vertical channeling effect through which R&D in the primary agricultural sector increases exports of processed food products.

Key words: agriculture, food, gravity equation, innovation, OECD, R&D

Introduction

With advances in globalization, innovation has taken on greater importance. One of the desired effects of innovation is to promote the lower cost of goods over time, space, and form (e.g., attributes such as variety, safety, quality, etc.). According to Shy (1996), innovation is "the search for, and the discovery, development, improvement, adoption, and commercialization of new processes, new products, and new organizational structures and procedures" (p. 221). This definition is sufficiently broad to encompass a variety of different aspects of innovation and technological adoption. Although the description and measurement of how innovation affects the level of prosperity in the agricultural sector has been well documented (Alston, Norton, and Pardy, 1995), the impact of an increased investment in innovation on the level of trade is a topic that has received scant attention in the agricultural economics literature.[1] This paper uses a gravity equation to measure the impact of innovation on trade in the primary agricultural and food processing sectors for Organization for Economic Cooperation and Development (OECD) countries.

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Review coordinated by David K. Lambert.

[1] One of the few related studies was conducted by Gopinath and Kennedy (2000). They found evidence that productivity growth (measured by total factor productivity) and factor accumulation have enhancing effects on U.S. agricultural trade flows.

Innovation is thought to influence the level of trade in three important ways:

- First, innovation may result in increased product differentiation, which provides consumers with either more variety choice and/or higher quality products. Hence, product differentiation can lead to the opening up of new consumer markets.

- Second, innovation lowers the cost of production. This is consistent with the textbook explanation of innovation which shifts the supply curve outward. A variant of the sector-specific cost-reducing innovation is the general (non-sector-specific) cost-reducing innovation. For example, innovation leading to reductions in transportation and infrastructure costs may eventually increase exports. Countries with enhanced roads, telecommunications networks, and internet capacity are able to increase trade due to the lower costs of conducting business (Bougheas, Demetriades, and Morgenroth, 1999; Freund and Weinhold, 2004; Martínez-Zarzoso and Márquez-Ramos, 2005).

- Finally, innovation can reduce transaction costs along the supply chain and make exports more competitive. For example, new business arrangements, such as improved inventory control, can increase the competitiveness of a firm and lead to an increase in trade.

The effect of innovation is not always to increase exports. Innovation associated with differentiated/higher quality products can cause some firms to gain market power and increase their markups beyond direct costs. In the longer run, when spillover and imitation do not induce fast erosion of the price markup, innovation would lead to a decrease in exports. This outcome occurs when there is some degree of appropriation of innovation (e.g., creating a brand name around the new differentiated product or an effective patent system). To this end, the effect of innovation on trade is at best ambiguous. One can draw a correspondence between the countervailing effects of innovation and those associated with the stringency of a patent regime applied by the importing country (Maskus and Penubarti, 1997; Smith, 1999; Co, 2004). The stringency of the patent regime leads to a market expansion effect for the foreign innovating firm while at the same time providing the firm with market power. Consequently, due to these countervailing effects, the net effect of the stringency of the patent regime on the volume of exports is not known a priori. In this study, the market expansion and market power effects of innovation arise through the actions undertaken by the exporters (e.g., R&D expenditure) rather than by the importers (e.g., patent regime applied by the importing country).[2]

This paper focuses on the effect that innovation has on exports in the primary agricultural and food processing sectors. We employ R&D expenditure to measure innovation. In the absence of superior measures of innovation, the selection of R&D expenditure as a proxy for innovation is dictated by the availability of comparable panel data sets across the OECD countries.[3] Meanwhile, we account for Griliches' (1979) arguments by

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[2] Grossman and Helpman (1991, chapter 9) addressed the implications of trade on innovation and economic growth. These issues are beyond the scope of this paper.

[3] See Cohen and Levin (1989) for a discussion on the problems associated with the different proxies of innovation that are commonly employed in empirical analyses (e.g., R&D expenditure, patent counts, personnel engaged in R&D).

employing the R&D capital stock as a more appropriate proxy for innovation, following Huffman and Evenson (2006).[4]

There is an empirical literature which reports the effects of national R&D expenditures on productivity (e.g., Hall and Mairesse, 1995; Zachariades, 2004; Acharya and Coulombe, 2006) and the international spillover effects of R&D on productivity (e.g., Coe and Helpman, 1995; Keller, 2002; Luintel and Khan, 2004). While the potential productivity effects of R&D may well increase exports, other effects of R&D (e.g., product differentiation, new products) may impact exports as well. Given that the measure of R&D used in this study encompasses a variety of different aspects of innovation, we attempt to directly measure the overall net effect of national R&D on exports. Hence, innovation is not restricted to a particular category (e.g., differentiated/higher quality products, lower production/transaction costs), but encompasses its various components.

In this investigation, the empirical application is guided by a theoretical gravity model that accounts for the effect of innovation. Gravity-based models relating trade to technology are well known in the literature. For instance, Eaton and Korutm (2002) developed a Ricardian model relating trade to geographic and comparative advantage factors (technology). Eaton and Korutm derived an equation resembling the standard gravity equation. Using a cross-sectional data set covering trade in manufacturing of 19 OECD countries in 1990, they estimated the structural parameters of the model and examined the gains from trade, the role of trade in spreading new technology, and the tariff-reduction effect. Martínez-Zarzoso and Márquez-Ramos (2005) applied a gravity equation to examine innovation as both a mechanism to reduce transaction costs via enhanced transport and internet infrastructure as well as a way to increase a country's technology endowment. Both reduced costs and increased technology endowment are hypothesized, and empirically found to increase exports.[5]

This study derives the gravity equation relating trade to innovation within a Heckscher-Ohlin framework for the primary agricultural sector based on Deardorff's (1998) contribution, and within the Dixit and Stiglitz (1977) framework with differentiated products for the food processing sector. The derived gravity equation accounts for R&D, and leads to an empirical model for testing the effect of R&D and hence innovation on trade. The empirical analysis is conducted over the period 1990–2003, covering 21 OECD countries. The effect of R&D on trade is not anticipated a priori due to the countervailing market expansion and market power effects. We also investigate the occurrence of the vertical channeling effect of R&D in the primary agricultural sector on exports of processed food products.[6]

The remainder of the paper is outlined as follows. First, a theoretical gravity-based model that accounts for innovation is derived. Next, the empirical specification is presented, followed by a description of the data and their sources. The estimation strategies and results are then discussed. Concluding remarks are presented in the final section.

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[4] Griliches (1979) argued that an appropriate proxy of innovation should not be the knowledge generated by R&D in one period, but the accumulated R&D stock built by placing relevant depreciation rates and accounting for the gestation period.

[5] Other papers have also examined the effect of enhanced infrastructure on trade. See, among others, Bougheas, Demetriades, and Morgenroth (1999) and Freund and Weinhold (2004).

[6] There is a strand of literature that focuses on examining trade effects on technology and innovation. For example, Coe and Helpman (1995) addressed the question of whether R&D spillovers are trade related. This issue is not addressed in our study.

Theoretical Model

Conventional modeling approaches for agricultural markets assume that primary commodities are homogeneous products, whereas food processors are assumed to produce differentiated goods (varieties). These presumed differences in product characteristics are consistent with two different theoretical frameworks when deriving the gravity equation. For the primary agricultural sector, we adopt a Heckscher-Ohlin framework to derive the gravity equation, building on Deardorff's (1998) contribution. The Heckscher-Ohlin model allows for one equilibrium with a nonequalization of factor prices (i.e., outside the factor-price equalization zone), which is considered in our case. With barriers to trade, factor prices may differ across countries. If not, then exports would not occur as they would not overcome the trade barriers. As in Deardorff (1998), a complete specialization in a given agricultural product (product mix) by each country is assumed. For the food processing sector, we derive the gravity equation from the conventional Dixit and Stiglitz (1977) framework of product differentiation with a constant elasticity of substitution (CES) between varieties. This paper accounts for innovation as a factor affecting trade in the theoretical gravity model.

Consider a world consisting of M ($m = 1, ..., i, j, ..., M$) countries and three sectors: a primary agricultural sector (A), a food processing sector (F), and a remaining sector (R). The preferences of the representative consumer are represented by a two-tiered utility function. The upper tier is a Cobb-Douglas function that determines the budget allocation across sectors. The lower tier is a CES function that describes the distribution of the consumer's budget among goods/varieties. The upper-tier utility function of the representative consumer of country i is given by:

$$\ln(U_i) = \lambda_i^A \ln(u_i^A) + \lambda_i^F \ln(u_i^F) + \lambda_i^R \ln(u_i^R),$$

where λ_i^A, λ_i^F, and λ_i^R are the share of total expenditure associated with sectors A, F, and R, respectively; u_i^A, u_i^F, and u_i^R are the lower-tier utility functions for A, F, and R, respectively.[7] Despite starting from different theoretical frameworks, the mathematical derivations in the primary agricultural sector and the food processing sector are equivalent. Therefore, we let $X \equiv A, F$ throughout the theoretical section, but we discuss the different theoretical interpretations associated with each sector. Accordingly, the lower-tier utility functions for the primary agricultural products and the processed food products are given as:

$$u_i^X = \left[\sum_{m=1}^{M} n_m^X \left(\beta_m^X c_{im}^X\right)^{(\sigma^X-1)/\sigma^X} \right]^{\sigma^X/(\sigma^X-1)}, \tag{1}$$

where σ^A and σ^F represent the CES between different primary agricultural goods and between different varieties of processed food products, respectively; n_m^A and n_m^F are the number of identical primary agricultural farms and food processing firms of country m,

[7] A primary agricultural product enters directly into the utility function (e.g., milk) and indirectly when it is further processed (e.g., milk that is processed into cheese). The inclusion of the primary product in its intermediate aspect in the utility function depicts the equivalence of its contribution in the utility derived from the corresponding value-added product. Also, given the high level of aggregation, the budgets allocated to the primary and processing sectors are assumed to be predetermined.

respectively; c_{im}^A is country i's consumption of the primary agricultural product produced by a farm in m; c_{im}^F is country i's consumption of the processed food variety produced by a firm in m; and β_m^X is the preference weight attached to the consumption of c_{im}^X. Each lower-tier utility function is maximized subject to the following budget constraint:

$$\text{(2)} \qquad \lambda_i^X Y_i = \sum_{m=1}^{M} n_m^X p_{im}^X c_{im}^X,$$

where p_{im}^A and p_{im}^F are the consumer prices in country i of the primary agricultural product and processed food variety exported by m, respectively. Maximizing (1) subject to (2), the first-order conditions result in:

$$\frac{c_{im}^X}{c_{im'}^X} = \left(\frac{p_{im}^X}{p_{im'}^X}\right)^{-\sigma^X} \left(\frac{\beta_{m'}^X}{\beta_m^X}\right)^{1-\sigma^X} \quad \forall\, m, m'.$$

Solving for c_{im}^X for all m yields the following total bilateral value of exports from a given country j to country i in the primary agricultural and food processing sectors:

$$\text{(3)} \qquad T_{ij}^X = n_j^X c_{ij}^X = \lambda_i^X Y_i n_j^X \left(\frac{p_{ij}^X}{\beta_j^X}\right)^{1-\sigma^X} \left(\frac{1}{P_i^X}\right)^{1-\sigma^X},$$

where P_i^A and P_i^F are the CES consumer price indices of country i in the primary agricultural sector and the food processing sector, respectively, and are determined as:

$$P_i^X = \left(\sum_{m=1}^{M} n_m^X \left(\frac{p_{im}^X}{\beta_m^X}\right)^{1-\sigma^X}\right)^{1/(1-\sigma^X)}.$$

A common approach in deriving the gravity equation is to exploit the market-clearing condition (Anderson and van Wincoop, 2003). In order to allow for an explicit accounting of innovation, we do not pursue this approach. Instead, we disentangle the elements of consumer prices into a unit production cost; delivery "costs" (e.g., tariffs, distance, geographic, and linguistic barriers); and a potential markup. Consider a Cobb-Douglas production function with G^X inputs defined as:

$$Z_j^X = \delta_j^X \prod_{g=1}^{G^X} \left(H_{gj}^X\right)^{\xi_g^X},$$

where Z_j^X is the total output per farm/firm in country j, δ_j^X is country j's total factor productivity in sector X, H_{gj}^X is the gth primary/intermediate production input in sector X, and ξ_g^X is the cost share of the gth input. Letting

$$\sum_{g=1}^{G^X} \xi_g^X = 1,$$

the constant returns-to-scale unit cost function for the primary agricultural sector and the food processing sector of country j is denoted by:

$$\varpi_j^X = k^X \frac{1}{\delta_j^X} \prod_{g=1}^{G^X} \left(w_{gj}^X\right)^{\xi_g^X},$$

where

$$k^X = \prod_{g=1}^{G^X} \left(\xi_g^X\right)^{-\xi_g^X}$$

is a constant term, and w_{gj}^X is the price of the gth input in country j.

Delivering goods from one location to the other is assumed subject to iceberg costs (Samuelson, 1952). When $\tau_{ij}^A > 1$ units of primary agricultural product and $\tau_{ij}^F > 1$ units of processed food variety are exported from country j to country i, one unit reaches the shore of the destination country. We write:

$$p_{ij}^X = k^X \mu_j^X \frac{1}{\delta_j^X} \tau_{ij}^X \prod_{g=1}^{G^X} \left(w_{gj}^X\right)^{\xi_g^X}, \tag{4}$$

where μ_j^X depicts the potential (exogenous) markup in sector X. Substituting (4) into (3) and arranging the logarithmic version of the equation, we obtain:

$$\begin{aligned} \ln(T_{ij}^X) = {} & \ln(k^X)^{1-\sigma^X} + \ln(\delta_j^X)^{\sigma^X-1} - \ln(\mu_j^X)^{\sigma^X-1} + \ln(\lambda_i^X Y_i) + \ln(n_j^X) \\ & + \ln(\beta_j^X)^{\sigma^X-1} - \sum_{g=1}^{G^X} \ln(w_{gj}^X)^{\xi_g^X(\sigma^X-1)} - \ln(\tau_{ij}^X)^{\sigma^X-1} + \ln(P_i^X)^{\sigma^X-1}. \end{aligned} \tag{5}$$

The common prima facie expectation is that an increase in R&D will eventually lead to an increase in exports. This is the market expansion effect. Assuming δ_j^X and β_j^X are increasing functions of R&D, the market expansion effect is expressed through their increase.[8] In addition, we specify n_j^X as a multiplicative function of the basic production capacity characterizing country j that is independent of R&D ($\bar{n}_j^X$) and a term depicting the positive effect of R&D on the number of goods/varieties (ϕ_j^X). Hence, the market expansion effect is also expressed through an increase in ϕ_j^X.[9] We write:

$$n_j^X = \bar{n}_j^X \phi_j^X. \tag{6}$$

The market expansion effect is countered by the market power effect, as higher R&D may eventually confer market power and therefore decrease trade. The market power effect is expected to be more prominent in the food processing sector due to the higher degree of product differentiation. The market power effect is depicted by an increase in μ_j^X that is accompanied by an increase in σ^X. After substituting (6) into (5), we define the following function of R&D:

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[8] The effect of R&D leading to higher quality products that satisfy consumer preferences can be expressed through an increase in the preference weights (i.e., β_j^X).

[9] One can argue that innovation may lead to the "profit destruction" of some other firms due to Schumpeter's (1934) phenomenon of "creative destruction" that is prominently addressed in the literature (e.g., Grossman and Helpman, 1991; Aghion and Howitt, 1992). As a result, some firms (and hence varieties) may be driven out of the market. While our model does not specify the mechanism by which the firms are driven out of the market, it still captures the outcome. When such phenomena occur, the term ϕ_j^X will be reflecting the net effect of innovation on the number of varieties (i.e., the increase in the number of varieties due to innovation and the decrease in the number of varieties when the corresponding firms are driven out of the market).

(7) $$\theta_j^X = \phi_j^X \left(\frac{\delta_j^X \beta_j^X}{\mu_j^X} \right)^{\sigma^X - 1}.$$

The occurrence of the markup is an empirical exercise. For example, if there are free entry and fast imitation leading to complete erosion of the markup, then μ_j^X will approach one. Conversely, if entry and imitation are limited, then μ_j^X is of higher magnitude.

Empirical Specification

We wish to estimate the overall effect of innovation (via R&D) on exports, as conceptually expressed through equation (5). The empirical analysis involves estimating a reduced-form equation that includes the variables suggested by the theoretical framework in (5). We follow the literature (e.g., Head and Mayer, 2000; Anderson and van Wincoop, 2003) by assuming a decomposition of the trade barriers into:

$$\tau_{ij}^X = TAR_{ij}^X DIST_{ij}^{\gamma_1} \exp(\gamma_2 LANG_{ij} + \gamma_3 CONT_{ij}),$$

where TAR_{ij}^X is the ad valorem tariff imposed by i on the imports from j, $DIST_{ij}$ is the distance between i and j, $CONT_{ij}$ is a dummy variable that takes the value of unity when the trading partners are contiguous, and $LANG_{ij}$ is a dummy variable that takes the value of unity when the trading partners speak a common language. Equation (5) yields the following reduced-form equation specified for panel data:

(8) $$\begin{aligned} \ln(TRADE_{ijt}^X) = {} & \alpha_0 + \alpha_1 \ln(RD_{jt}^X) + \alpha_2 \ln(GDP_{it}) + \alpha_3 \ln(IINPV_{jt}^X) + \alpha_4 \ln(r_{jt}) \\ & + \alpha_5 \ln(w_{jt}) + \alpha_6 \ln(DIST_{ij}) + \alpha_7 CONT_{ij} + \alpha_8 LANG_{ij} \\ & + \alpha_9 EU + \alpha_{10} NAFTA + \alpha_{it} + u_{ijt}, \end{aligned}$$

where $TRADE_{ijt}^X$ is the deflated value of exports from j to i at time t. The regressor of interest is RD_{jt}^X, representing the R&D capital in country j at time t. For the food processing sector, equation (8) is augmented by $\ln(RD_{jt}^A)$, reflecting the potential effect of R&D in the primary agricultural sector on trade in the food processing sector. The coefficient on $\ln(RD_{jt}^X)$ reflects the net outcome of the market expansion and the market power effects; thus the sign is not known a priori.

For the remaining regressors, GDP_{it} is the deflated value of the gross domestic product proxying for market demand; $IINPV_{jt}^A$ and $IINPV_{jt}^F$ are the deflated values of intermediate inputs in A and F proxying for the supply capacity;[10] and r_{jt} and w_{jt} are the capital rent and labor wage prevailing in the producer country j at time t. Cross-border trade policy barrier (i.e., TAR_{ijt}) is decomposed into a common applied most-favored-nation (MFN) rate at time t captured by the destination country-by-time fixed effect (α_{it}) and a preferential rate captured by employing regional trade agreement (RTA) dummy variables that take the value of unity when both trading partners belong to a given RTA.

[10] The value added and the value of total production may reflect some effects of innovation. Therefore, the value of intermediate inputs is employed instead to proxy for the supply capacity.

The RTA dummy variables are: (*a*) *EU* for the European Union, and (*b*) *NAFTA* for the North American Free Trade Agreement, which came into effect in 1989 through the Canada-U.S. Free Trade Agreement and was extended in 1994 to include Mexico. The CES consumer price index of the destination country is captured by the country-by-time fixed effect (α_{it}).[11] The error term is denoted by u_{ijt}. Note that the effect of GDP_{it} is controlled by the destination country-by-time fixed effect. As the value of its coefficient is relative to the dropped fixed-effect dummy variable, it is not reported in the empirical tables.

Data

Bilateral trade values for the primary agricultural and food processing sectors are collected from the OECD's Structural Analysis (STAN) bilateral trade data sets. The sectors in the STAN data sets are classified according to the International Standard Industrial Classification-Revision 3 (ISIC Rev. 3). The primary agricultural sector is the aggregate of ISIC Rev. 3 classes A (agriculture, hunting, and forestry) and B (fishing). The food processing sector is the aggregate of ISIC Rev. 3 classes D-15 (manufacture of food products and beverages) and D-16 (manufacture of tobacco products).

Dictated by the availability of the data sets, governmental R&D outlays are employed to depict the R&D in the primary agricultural sector, and are collected from the OECD data set on government budget appropriations or outlays for R&D with the objective specified as agricultural production and technology.[12] R&D in the food processing sector is measured by the total R&D expenditure in the food processing sector by all firms, compiled from the STAN R&D expenditure in industry data sets. R&D is represented by the accumulated capital stock from 1987, in accordance with time-weighting patterns as reported in Huffman and Evenson (2006). Specifically, after two years of a gestation period during which the impact of R&D on trade is considered negligible, the impact becomes positive with linearly increasing weights over the next seven years. Then, there is a period of six years of maturity with constant weights, after which there is a linear decline in weighting over 20 years.

Intermediate input values are sourced from the STAN industrial data sets. Following Antweiler and Trefler (2002), capital rents are proxied by the price of investment compiled from the World Penn Table 6.1. Labor compensation per worker is used as the wage variable. Labor compensation and total employment are compiled from STAN industrial data sets. GDP values are sourced from the *OECD Economic Outlook*. The annual exchange rates and GDP deflators, also sourced from the *OECD Economic Outlook*, are used to convert the values in local currency into U.S. dollar equivalents and to deflate the U.S. dollar values, respectively. We use Head and Mayer's (2000, 2002) distance measure between two countries that accounts for the dispersion of the economic

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[11] The control of the CES consumer price index (multilateral resistance in the terminology of Anderson and van Wincoop, 2003) by a fixed-effect term is a common practice in the gravity literature (e.g., Feenstra, 2002; Subramanian and Wei, 2007). Some authors employed price indices such as the GDP deflator and the consumer price index (CPI) to proxy for the CES consumer price index when the analysis is conducted for the aggregate trade flow between countries (e.g., Baier and Bergstrand, 2001). In our case, the CES consumer price index is sector specific, and thus the appropriate CPI is unfortunately not available.

[12] Data sets on the actual governmental R&D expenditure in the primary agricultural sector are limited. Therefore, we employ the government budget appropriations or outlays for R&D with the objective specified as agricultural production and technology to capture the effect of R&D in the primary agricultural sector.

activities within each country. The data set is obtained from the Centre d'Études Prospectives et d'Informations Internationales.[13]

Estimation Strategy and Results

There are some issues that need to be addressed when estimating equation (8). First, nonspherical error terms resulting from heteroskedasticity, autocorrelation, and contemporaneous correlation across panel sets are anticipated in the data set. Heteroskedasticity may occur because trade between two smaller countries or between a smaller country and a larger country is likely to be more volatile compared to trade between two larger countries (Frankel, 1997).[14] Autocorrelation within panels may be present, partly reflecting sunk-cost effects (Roberts and Tybout, 1997). Contemporaneous correlation across panels may exist in the data set because exporting to one country can take place as an alternative (or perhaps as a complement) to exporting to another country, or because adjacent importer(s)'/exporter(s)' time-specific shocks result in larger correlated error terms of their trade with their partners. Building on Hicks' (1994) illustration, it is likely that the error terms associated with exports of a given country to Sweden and Norway bear some resemblance. In this sense, the error terms associated with exports to the Scandinavian countries may be linked but independent of the error terms associated with exports to, for example, the North American countries. In our data set, the number of panels exceeds the number of time periods, so feasible generalized least squares (FGLS) estimation cannot account for contemporaneously correlated panel sets. Therefore, we address the contemporaneous correlation issues by applying a variant of the FGLS, the panel corrected standard error (PCSE) approach, which controls for heteroskedasticity, AR(1) type of autocorrelation with a common parameter across panels, and contemporaneous correlation across panels (Beck and Katz, 1995, 1996).[15]

Another concern stems from employing sector-specific wages. Wages paid in the primary agricultural and food processing sectors might partially reflect the effects of R&D since R&D may potentially lead to higher wages. To tackle this potential issue, we use the wages prevailing in the manufacturing sector exclusive of the food processing sector, hence independent of the R&D expenditure in the agricultural and food processing sector.[16]

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[13] For the primary agricultural sector, observations exist for the following 21 OECD countries: Australia, Belgium-Luxemburg, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Mexico, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States. The data set extends over the period 1990 through 2003. Hence, it consists of $21 * 20 * 14 = 5{,}880$ bilateral observations. For the food processing sector, due to data limitations, the OECD source countries consist of the following 14 countries: Australia, Belgium-Luxemburg, Canada, Denmark, Finland, France, Ireland, Italy, Japan, the Netherlands, Norway, Sweden, the United Kingdom, and the United States. The data set equivalently covers the period 1990–2003, consisting of $14 * 20 * 14 = 3{,}920$ observations.

[14] In a cross-sectional setting, Frankel (1997) suggested that trade of larger countries should be given more weight. He argued that the use of economic-size-weighted least squares induces the regression to rely more on information extracted from the exchange between larger countries.

[15] To deal with the heteroskedasticity, autocorrelation, and contemporaneous correlation across panels, Parks (1967) pioneered a feasible generalized least squares method. Beck and Katz (1995) argued, through Monte Carlo simulation, that Parks' (1967) method results in standard errors that lead to extreme overconfidence, hence reducing the variability. Moreover, Parks' (1967) method requires that $T > N$ (which is not the case in our data sets). To tackle heteroskedasticity, and contemporaneous correlation, Beck and Katz (1995) developed an alternative method that uses OLS parameter estimates and replaces the OLS standard errors with panel-corrected standard errors. Beck and Katz (1995) also showed that, if autocorrelation is suspected, the Prais-Winsten estimators with panel-corrected standard errors should be used. Beck and Katz (1995, p. 121) argued in favor of estimating a single AR(1) parameter rather than panel-specific AR(1) parameters.

[16] Reallocation of labor across the industries following an increase in wages is expected to be imperfect due to the specialized labor in each industry.

Table 1. Estimation Results: Primary Agricultural Sector

Variable	Coefficient	z-Value
$\ln(RD_{jt}^{A})$	0.789***	0.171
$\ln(IINPV_{jt}^{A})$	0.474***	0.128
$\ln(r_{jt})$	-0.684**	0.332
$\ln(w_{jt})$	-0.071	0.079
$\ln(DIST_{ij})$	-1.029***	0.068
$LANG_{ij}$	0.368***	0.136
$CONT_{ij}$	0.427***	0.089
EU	0.868***	0.148
$NAFTA$	1.097***	0.403
R^2 = 0.707		
rho = 0.820		
No. of Observations = 5,880		

Notes: Single, double, and triple asterisks (*) denote statistical significance at the 10%, 5%, and 1% levels, respectively. The dependent variable is $\ln(TRADE_{ijt}^{A})$. Parameters are estimated by the Prais-Winsten estimator. The common AR(1) parameter is denoted by rho. The z-values are constructed from standard errors that are corrected for heteroskedasticity and contemporaneous correlation of error terms across panels.

The results of equation (8) for the primary agricultural sector are presented in table 1. The coefficient on $\ln(RD_{jt}^{A})$ is positive and significant at the 1% level, indicating a positive effect of R&D (and innovation) on exports from the primary agricultural sector of country j. For each 10% increase in R&D capital, there is a 7.9% increase in exports of primary agricultural products. The positive impact of R&D on exports of primary agricultural products is an important result with significant policy implications. Countries desiring to increase their exports of primary agricultural products may do so through, for example, trade agreements and improved domestic infrastructure. One additional way to increase exports is through R&D expenditure which makes the primary agricultural sector more productive with enhanced product attributes.

The coefficient on *EU* is positive and significant at the 1% level, indicating that EU members trade 2.4 times [= exp(0.868)] more with each other in primary agricultural products compared to trade between OECD countries not sharing a membership in any RTA. Similarly, the coefficient on *NAFTA* is positive and significant at the 1% level, implying that NAFTA members trade 3.0 times [= exp(1.097)] more with each other than otherwise. It is important to note that caution is warranted in interpreting the coefficients of RTA dummy variables, as they do not necessarily reflect the effect of the RTA implementation per se.[17] The coefficient on capital rent is negative and significant, as expected. The coefficient on the wage rate variable is found to be insignificant. The remaining variables (distance, contiguity, and common language) are all significant with the expected signs.

[17] Eichengreen and Irwin (1995, 1998) showed that RTA dummy variables have positive and significant coefficients long before the actual implementation of the RTAs. Therefore, ambiguity arises as to whether the higher trade between members of RTAs is indeed attributable to the RTAs per se. The authors argued that these outcomes reflect historical trade-related patterns.

Table 2. Estimation Results: Food Processing Sector

Variable	Coefficient	z-Value
$\ln(RD_{jt}^F)$	-0.570***	0.114
$\ln(RD_{jt}^A)$	0.735***	0.118
$\ln(IINPV_{jt}^F)$	1.070***	0.138
$\ln(r_{jt})$	-0.401*	0.226
$\ln(w_{jt})$	-0.644***	0.114
$\ln(DIST_{ij})$	-0.995***	0.062
$LANG_{ij}$	0.954***	0.070
$CONT_{ij}$	0.340***	0.107
EU	1.149***	0.211
$NAFTA$	0.301	0.210
R^2 = 0.913		
rho = 0.893		
No. of Observations = 3,920		

Notes: Single, double, and triple asterisks (*) denote statistical significance at the 10%, 5%, and 1% levels, respectively. The dependent variable is $\ln(TRADE_{ijt}^F)$. Parameters are estimated by the Prais-Winsten estimator. The common AR(1) parameter is denoted by rho. The z-values are constructed from standard errors that are corrected for heteroskedasticity and contemporaneous correlation of error terms across panels.

The results of equation (8) for the food processing sector are reported in table 2. The coefficient on RD_{jt}^F is negative and significant at the 1% level. This result implies that the market power effect of R&D is more than offsetting its market expansion effect in the food processing sector. A 10% increase in R&D capital leads to a net reduction of 5.7% for processed food exports. Based on equation (7), this result suggests an increase in the markups associated with the increase in R&D capital. If free entry into the sector is limited, due to patents or large sunk costs, for example, firms may be able to charge and maintain markups. Because most of the R&D in the food processing sector is funded by the private sector, it is not surprising that it would lead to higher markups.[18] The coefficient on RD_{jt}^A is found to be positive and significant at the 1% level, suggesting a vertical channeling effect of R&D in the primary agricultural sector on exports of processed food products. A 10% increase in R&D capital in the primary agricultural sector leads to an increase of 7.4% in the exports of processed food products.

The estimated coefficient on *EU* is positive and significantly different than zero at the 1% level, indicating that EU members trade 3.2 times [= exp(1.149)] more with each other in processed food products compared to trade between OECD countries not sharing a membership in any RTA. On the other hand, there is a positive coefficient on *NAFTA* that is insignificantly different from zero at the 10% level. The coefficients on the wage rate and capital rent are both negative and significant at the 1% and 10% levels, respectively. The estimated coefficients on distance, contiguity, and common language are significant with the expected signs.

[18] This outcome is consistent with the endogenous growth theory.

Perhaps the most interesting result in the analysis is the negative sign on the R&D capital variable in the food processing trade equation. While we attribute this result to the increased markups caused by enhanced market power, more can be said. The food sector in many OECD countries has increased in market concentration since the 1980s (USDA, 2002; Eurostat, 2003). This increase in concentration is due in part to product and technological innovation, but also is explained by agglomeration effects brought about by supply chain management strategies, which constitute another form of innovation. Sorting out this phenomenon on food prices and trade is a challenge needing to be examined further.

Conclusion

The gravity equation is shown to be a useful framework for estimating the impact of innovation on exports of primary agricultural and processed food products. Empirical results show that R&D has different effects across sectors. We found that R&D has a net positive market expansion effect on exports of primary agricultural products, as a 10% increase in R&D capital induces a 7.9% increase in exports. In the food processing sector, the market power effect appears to more than offset the market expansion effect to cause a decrease in exports. For each 10% increase in R&D capital, there is a 5.7% net reduction in exports. However, our findings reveal evidence of a positive vertical channeling effect through which R&D in the primary agricultural sector increases exports of processed food products.

This paper points to several interesting directions of future research for assessing how innovation affects exports of primary agricultural and processed food products. The robustness of the R&D responses should be ascertained by designing alternative measures of innovation. Measures such as the number of new products introduced, patents, and better and more detailed R&D expenditure data would be a good start. The countries considered in our data sample are mainly developed nations; it would be useful to consider trade between less developed countries.

Most agricultural R&D studies (e.g., Alston, Norton, and Pardy, 1995; Huffman and Evenson, 2006) have focused on estimating the domestic benefits of agricultural R&D. Our results shed new light on the benefits of agricultural R&D at the international level—both directly through primary agricultural exports and indirectly through enhancements of agri-food exports. Our analysis also suggests that R&D in the food processing sector induces firms to increase their markups. These results have implications for governmental policies. For the most part, governments have done little industrial R&D in the food processing sector, instead focusing mainly on making the primary agricultural sector more productive and on the development of products with enhanced attributes. Given our findings of the direct effects of agricultural R&D on agricultural trade and its complementary impact on food trade, this appears to have been a good strategy.

[*Received January 2007; final revision received September 2007.*]

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