"Eco-Labelling and the Gains from Agricultural and Food Trade: A Ricardian Approach"

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Abstract
Following a modern Ricardian approach, trade in environmental products with eco-labelling is modelled. Based on the model, expressions are derived for the share of products an importer purchases from a specific exporter for low-cost and environmentally-friendly technologies. It is then shown that, using bilateral trade and production data, the share equation for low-cost-technologies can be estimated, from which parameters describing trade costs and average productivity can then be retrieved. Using the latter parameters, it is also shown how the share equation for environmentally-friendly technologies can then be used to retrieve a parameter describing eco-labelling costs. The consumer and environmental gains from eco-labelling are also analyzed, along with a discussion and comparison of the effects of mutual recognition versus harmonization of countries’ eco-labelling regimes.

Keywords: trade, trade costs, eco-labelling, trade liberalization

JEL Codes: F11, F14, F15, Q17, Q56

Introduction

Sexton (2013) has recently argued that industrial organization analysis of the US food and agricultural marketing system should properly recognize food product differentiation, including claims of production being environmentally-friendly. Vertical product differentiation of this type often suffers from a key information failure: consumers are unable to verify claimed environmental benefits of how a product was produced both before and after consumption, such claims being termed as *credence* attributes of the product (Darby and Karni, 1973). Eco-labelling in conjunction with a mechanism for certification of environmental claims is regarded as key in resolving any information asymmetry due to products having credence attributes (Roe and Sheldon, 2007). In addition, in an international setting, the choice by trading partners between mutual recognition and harmonization of their eco-labelling standards becomes an important policy issue (Sheldon and Roe, 2009). Interestingly, a recent OECD survey (Gruére, 2013) indicates that there has actually been very rapid growth in total eco-labelling since the 1970s, and a significant portion of this growth has been in eco-labels relating to food and agricultural products, as well as textile and forest products. Breaking out the OECD into regions, the number of eco-labels in North America and Europe are dominated by products from the food and agricultural sector, with very few eco-labelled products in the Asian region of OECD, the labels covering characteristics such as waste, energy, natural resources, climate change, biodiversity and chemical control.

Models of the impact of trade on environmental quality have typically assumed that under certain conditions negative externalities will be generated with increased international integration, particularly between North and South (Copeland and Taylor, 2004). However, trade in products with credence attributes may generate environmental gains. Once production generates environmental benefits, this should be explicitly incorporated into trade analysis, and the associated evaluation of trade liberalization. In this paper a Ricardian-type trade model is developed that draws on the original analysis of Eaton and Kortum (2002), and more recently Fieler (2011). This class of model has already been applied to agricultural trade by Reimer and Li (2010), and recently by Heerman, Arita and Gopinath (2015). This type of model is adapted in this paper in order to evaluate the impact of trade liberalization in eco-labelled products.

In what follows, a simple illustrative model is described in section 1, highlighting the basic way in which eco-friendly products and labelling can be incorporated into a trade model. A more detailed model is derived in section 2 along with a solution methodology, followed in section 3 by a detailed description of how to calibrate the model for the purposes of policy simulation. Analysis of the consumer and environmental gains from trade and eco-labelling, and the effects of alternative policies towards eco-labelling are then presented in sections 4, 5 and 6 respectively. Finally, the paper is summarized and some conclusions about the future direction of this line of research are drawn in section 7.

1. An Illustrative Model

The basic story of the current paper is as follows: opening to trade offers buyers access to products produced using two types of production process by each of their trading partners. The least cost (LC) and most "environmentally-friendly" (EF) technologies. Eco-labels solving the credence attribute problem, allow consumers that are willing to pay a higher price for environmentally-friendly products to identify them and thus allow producers to be compensated for higher costs of production. Eco-labels increase the net environmental gains from trade by expanding the market share of products produced with more environmentally-friendly technology.

To illustrate, a simple two-country model can be described. The world is comprised of two countries with many representative buyers and a continuum of agricultural and food products. Each country has a unique technology for producing each product. All product markets are perfectly competitive. Unit costs of production for each country and product are plotted in figure 1. Products have been organized in order of increasing unit costs for Country 1 producers and decreasing unit costs for Country 2 producers. In autarky, both countries produce every agricultural product that has a less-than-infinite cost of production.

After opening to trade, buyers purchase each product from the country that has the lowest unit cost of production. Before trade, Country 1 buyers consume products from 0 to a_2 and Country 2 buyers consume products from a_1 to 1. After trade, buyers consume all products. Country 1 specializes in products 0 to b and Country 2 specializes in products from b to 1. The products in which a country has the lowest unit production costs require fewer inputs per unit of output. Notably, if it is assumed that fewer inputs imply a smaller environmental impact, there is an environmental gain $f(C)$, when Country 1 stops producing products b to a_2. This gain could be offset by the environmental impact of transporting products from Country 2, but this potential source of gains is abstracted from in the current paper.

Extending the analysis, producers have access to a second set of environmentally-friendly (EF) technologies. Unit costs of production for these products are higher because inputs are more costly. A subset of buyers is always willing to pay a higher price for EF products. Another subset of buyers will purchase EF products as long as the difference in price between the EF product and the product produced with the low cost (LC) technology is less than $\boldsymbol{w}$**.** In this case there is an environmental gain from trade that is a function of the share of buyers that always purchase environmentally-friendly products, α_E, those that purchase some EF products α_B and w, $f(\alpha_E, \alpha_B, w)$.

In terms of figure 2, after opening to trade, Country 1 will, in addition to producing products from 0 to b_L with LC technology, specialize in products from b_L to b_E, that are produced with EF technology. Eco-labels allow buyers who are willing to pay a higher price for EF products to identify them and allow producers to obtain compensation for using the EF technology. Thus eco-labelling provides Country 1 with the ability to capitalize on a comparative advantage in EF products from b_L to b_E.

In the very simple two-country world depicted in this section, trade gives buyers access to the lowest cost and most environmentally-friendly technologies in each of their trading partners. The role of an eco-label in this model is to allow consumers to exercise their preference for the EF technology over the LC technology and allow producers to be compensated by a higher price. This story can be easily extended to a many-country world using the probabilistic approach originally developed in Eaton and Kortum (2002). The key is to model unit costs for each product in each country as a random variable. Then, rather than conceptually organizing products on the continuum in order of unit costs, they can be organized according to any other classification system that is convenient, e.g., by something like an HS code with an infinite number of digits.

2. Full Model

There are I countries engaged in international trade of agricultural products. Following Dornbusch, Fischer and Samuleson (1977), a continuum of agricultural products indexed by j are produced in each country. Producers have access to two technologies for each product: low-cost (LC) technology and environmentally-friendly technology (EF):

$$q_i^{LC}(j) = z_i(j)L_i$$

$$q_i^{EF}(j) = z_i(j)L_i^{\alpha}H_i^{1-\alpha}$$

where $z_i(j)$ is a productivity-enhancing random variable. Both technologies require land L_i as an input. The EF technology also requires environmental services H_i. Assume $z_i(j)$ is distributed independently following a Frechet distribution:

$$F_i(z) = \exp\{-T_i z^{-\theta}\} \tag{1}$$

as in Eaton and Kortum. Then T_i describes average productivity in country i – higher values of T_i imply a country is more productive on average. The parameter θ describes the dispersion of productivity. A smaller θ implies larger productivity differences across products and countries. Comparative advantage thus presents a stronger force against trade costs. It also implies trade patterns are less sensitive to changes in trade costs.

Perfectly competitive producers set domestic prices equal to unit costs of production (see Appendix A). Producers in country i can export to market n, but face an iceberg transport cost $\tau_{ni} > 1$ to do so. *EF* producers must also pay a cost ζ_{ni} in excess of domestic labelling costs to meet country n labelling requirements. Therefore, exporter i's price offers in market n are:

(2) $$p_{ni}^{LC}(j) = \frac{r_i \tau_{ni}}{z_i(j)} \qquad p_{ni}^{EF}(j) = \frac{\kappa r_i^{\alpha} {w_i}^{1-\alpha} \tau_{ni} \zeta_{ni}}{z_i(j)}$$

where r_i is the land rental rate, w_i is the unit cost of environmental services and κ is a parameter (see Appendix A). In this model, the only source of variation across products comes from productivity differences $z_i(j)$. Thus, it is assumed that producers in country i have identical efficiency of producing j with the EF technology relative to LC technology for all products.[1]

Buyers in market n purchase each LC and EF product from the exporter with the lowest price offer. The price actually paid for product j in market n is therefore:

(3) $$p_n^k(j) = \min_i \{p_{ni}^k(j)\}$$

where $k = LC, EF$. To understand what this implies for the distribution of prices in importing country n, the productivity distribution (1) is made use of to first derive the distribution of price offers from exporter i in market n, $G_{ni}^{EF}(p)$:

$$\Pr\left(p_{ni}^{EF}(j) \le p\right) = \Pr\left(\frac{\kappa r_i^{\alpha} {w_i}^{1-\alpha} \tau_{ni} \zeta_{ni}}{z_i(j)} \le p\right)$$

$$= 1 - \Pr\left(z_i(j) \le \frac{\kappa r_i^{\alpha} {w_i}^{1-\alpha} \tau_{ni} \zeta_{ni}}{p}\right)$$

$$= 1 - F_i\left(\frac{\kappa r_i^{\alpha} {w_i}^{1-\alpha} \tau_{ni} \zeta_{ni}}{p}\right)$$

(4) $$= 1 - \exp\left\{-T_i (\kappa r_i^{\alpha} {w_i}^{1-\alpha} \tau_{ni} \zeta_{ni})^{-\theta} p^{\theta}\right\} \equiv G_{ni}^{EF}(p)$$

Equation (3) implies $p_n^{EF}(j) \le p$ unless all countries' price offers are greater than p:

[1] The amount of environmental input could also be modeled as product specific, i.e., $H_i(j)$ in order to accommodate different patterns of specialization across products under LC vs. EF technology.

$$\Pr(p_n^{EF}(j) > p) = \Pr\left(p_{nl}^{EF}(j) > p \ \forall l\right)$$

$$= \prod_{l=1}^{I}\left(1 - G_{ni}^{EF}(p(j))\right)$$

$$= \prod_{l=1}^{I} exp\left\{-T_l(\kappa r_l^{\alpha} w_l{}^{1-\alpha}\tau_{nl}\zeta_{nl})^{-\theta}p^{\theta}\right\}$$

$$= exp\left\{-\sum_{l=1}^{I} T_l(\kappa r_l^{\alpha} w_l{}^{1-\alpha}\tau_{nl}\zeta_{nl})^{-\theta}p^{\theta}\right\}$$

Therefore:

(5) $$\Pr\left(p_{nl}^{EF}(j) \leq p \ \forall l\right) = 1 - exp\left\{-\sum_{l=1}^{I} T_l(\kappa r_l^{\alpha} w_l{}^{1-\alpha}\tau_{nl}\zeta_{nl})^{-\theta}p^{\theta}\right\}$$

Notice that this expression is the same for all exporters. That is, the distribution of prices for products actually purchased from every exporter by importer n is identical. Therefore the distribution of prices for products actually purchased in market n is:

(6) $$\Pr(p_n^{EF}(j) \leq p) = 1 - exp\left\{-\Phi_n^{EF}p^{\theta}\right\} \equiv G_n^{EF}(p)$$

where $\Phi_n^{EF} = \sum_{l=1}^{I} T_l(\kappa r_l^{\alpha} w_l{}^{1-\alpha}\tau_{nl}\zeta_{nl})^{-\theta}$.

Equivalent expressions for the distribution of *LC* products can be obtained by setting $\alpha = \zeta_{ni} = 1$:

$$G_{ni}^{LC}(p) = 1 - exp\left\{-T_i(r_i\tau_{ni})^{-\theta}p^{\theta}\right\}$$

$$G_n^{LC}(p) = 1 - exp\left\{-\Phi_n^{LC}p^{\theta}\right\}$$

where $\Phi_n^{LC} = \sum_{l=1}^{I} T_l(r_l\tau_{nl})^{-\theta}$.

The Φ_n^k parameters describe how average productivity, input costs, trade costs and labelling costs around the world affect prices in each import market. Lowering trade and labelling costs increases Φ_{ni}^k and thus the average level of production efficiency of importer n consumption. To the extent that, higher production efficiency reflects a more suitable environment for production with a smaller negative environmental impact net of transport, lower trade costs enable consumption with a smaller environmental impact, even if consumption is not reallocated to EF products.

Using the price distributions (4) and (6), the probability that exporter i offers the lowest price for an EF product in importer n can be calculated. The probability the lowest price offer comes from exporter i is the probability that all of its competitors offer higher prices. Let $p_{ni}(j) = p^*$. Then:

$$\Pr\left(p_{nl}^{EF}(j) > p^* \;\forall l \neq i\right) = \prod_{l \neq i} \Pr\left(p_{nl}^{EF}(j) > p^*\right) = exp\left\{-\sum_{l \neq i} T_l (\kappa r_l^{\alpha} w_l{}^{1-\alpha} \tau_{nl} \zeta_{nl})^{-\theta} p^{*\theta}\right\}$$

Integrating over all possible realizations of $p_{ni}^{EF}(j)$:

$$\Pr\left(p_{nl}^{EF}(j) > p_{ni}^{EF}(j) \;\; \forall l \neq i\right) = \int exp\left\{-\sum_{l \neq i} T_l (\kappa r_l^{\alpha} w_l{}^{1-\alpha} \tau_{nl} \zeta_{nl})^{-\theta} p^{\theta}\right\} dG_{ni}^{EF}(p(j))$$

$$= \int exp\left\{-\sum_{l \neq i} T_l (\kappa r_l^{\alpha} w_l{}^{1-\alpha} \tau_{nl} \zeta_{nl})^{-\theta} p^{\theta}\right\} \exp\left\{-T_i (\kappa r_i^{\alpha} w_i{}^{1-\alpha} \tau_{ni} \zeta_{ni})^{-\theta} p^{\theta}\right\} \theta T_i (\kappa r_i^{\alpha} w_i{}^{1-\alpha} \tau_{ni} \zeta_{ni})^{-\theta} p^{\theta-1} dp$$

$$= \int exp\left\{-\Phi_n^{EF} p^{\theta}\right\} \theta T_i (\kappa r_i^{\alpha} w_i{}^{1-\alpha} \tau_{ni} \zeta_{ni})^{-\theta} p^{\theta-1} dp$$

Multiply by $\frac{\Phi_n^{EF}}{\Phi_n^{EF}} = 1$:

$$= \frac{T_i (\kappa r_i^{\alpha} w_i{}^{1-\alpha} \tau_{ni} \zeta_{ni})^{-\theta}}{\Phi_n^{EF}} \int \Phi_n^{EF} exp\left\{-\Phi_n^{EF} p^{\theta}\right\} \theta p^{\theta-1} dp$$

The expression under the integral is $dG_n^{EF}(p)$ and is thus equal to 1. Therefore:

(7) $$\Pr\left(p_{nl}^{EF}(j) > p_{ni}^{EF}(j) \;\; \forall l \neq i\right) = \frac{T_i \left(\kappa r_i^{\alpha} w_i{}^{1-\alpha} \tau_{ni} \zeta_{ni}\right)^{-\theta}}{\Phi_n^{EF}} \equiv \pi_{ni}^{EF}$$

since there is a continuum of EF products, this is also the fraction of products buyers in importer n purchase from exporter i. By setting $\alpha = \zeta_{ni} = 1$, the fraction of LC good purchased in market n from exporter i can similarly be defined:

(8) $$\pi_{ni}^{LC} = \frac{T_l (r_l \tau_{nl})^{-\theta}}{\Phi_n^{LC}}$$

Equations (7) and (8) are also the share of importer n expenditure on EF and LC products, respectively. To see this, notice that country n's average expenditure per good does not vary by source. The average price per type k good is the mean of the price distribution:

$$\int pdG_n^k(p)$$

Since $G_n(p)$ is also the distribution of prices for products purchased from country i, this is also the average price for a good purchased from exporter i. Total expenditure on type k products can thus be written:

$$X_n^k = \int_0^1 Q^k(j)dj \int_0^\infty pdG_n^k(p)$$

Since π_{ni}^k is the share of products purchased from country i:

$$X_{ni}^k = \pi_{ni}^k \int_0^1 Q^k(j)dj \int_0^\infty pdG_n^k(p)$$

Therefore:

$$\frac{X_{ni}^k}{X_n^k} = \frac{\pi_{ni}^k \int_0^1 Q^k(j)dj \int_0^\infty pdG_n^k(p)}{\int_0^1 Q^k(j)dj \int_0^\infty pdG_n^k(p)} \equiv \pi_{ni}^k$$

Buyers have preferences over agricultural products produced with each technology. EF products have credence attributes – but the production method does not alter a product's intrinsic characteristics as they are perceived by consumers, and EF products have higher costs of production and thus higher prices. Therefore, buyers only choose EF products if they are labelled as such. With labelling, buyers choose quantities of each type of product to maximize:[2]

$$\frac{\sigma}{\sigma-1}\left(\int_0^1 q_i^{LC}(j)^{\frac{\sigma-1}{\sigma}}dj + \omega_i^{\frac{1}{\sigma}}\int_0^1 q^{EF}(j)^{\frac{\sigma-1}{\sigma}}dj\right)$$

where ω_i is a weight representing the value buyers place on EF methods. This implies total expenditure on EF products relative to LC products is (see Appendix B)

$$\frac{X_i^{EF}}{X_i^{LC}} = \omega_i\left(\frac{P_i^{EF}}{P_i^{LC}}\right)^{1-\sigma} \qquad (9)$$

where P_i^k is a CES price index for products produced with type k technology (see Appendix C):

[2] These preferences follow those described in Fieler (2011), except here for simplicity, they are assumed to be homothetic. However, if $\sigma_{LC} \neq \sigma_{EF}$, income effects can also be derived.

(10) $$P_i^k = \gamma \Phi_n^{k\frac{1}{\theta}} \quad k = LC, EF$$

where γ is a function of parameters.

Given parameters capturing average technology levels (T_i), bilateral trade costs (τ_{ni}), bilateral labelling costs (ζ_{ni}), an *EF* value weight (ω_i) and the Lagrange multiplier (λ_i), equilibrium is rental rates (r_i), the value of environmental services ($w_i H_i$), bilateral expenditure shares ($\pi_{ni}^{LC}, \pi_{ni}^{EF}$), an allocation of buyer expenditure $\left(X_i^{LC}, X_i^{EF}\right)$ and land resources $\left(L_i^{LC}, L_i^{EF}\right)$ across *LC* and *EF* products such that labor markets clear and trade is balanced.

To solve the model for equilibrium Levchenko and Zhang (2011) are followed. From the consumer's problem (Appendix B), total demand for EF and LC products in country n are, respectively:

$$X_i^{EF} = \lambda_i^\sigma \omega_i P_i^{EF^{1-\sigma}}$$

$$X_i^{LC} = \lambda^\sigma P_i^{LC^{1-\sigma}}$$

Total exports of type k products are $EX_n^k = \sum_{i \neq n} \pi_{in}^k x_i^k$ and total imports are $IM_n^k = \sum_{i \neq n} \pi_{ni}^k x_n^k$. Trade balance requires:

$$\sum_{k=EF,LC} EX_n^k = \sum_{k=EF,LC} IM_n^k$$

Product market clearing implies:

$$Y_i^{EF} = \sum_{i=1}^{I} \pi_{in}^{EF} X_n^{EF} = \sum_{i=1}^{I} \pi_{in}^{EF} \lambda_n^\sigma \omega_n P_n^{EF^{1-\sigma}}$$

$$Y_i^{LC} = \sum_{i=1}^{I} \pi_{in}^{LC} X_n^{LC} = \sum_{i=1}^{I} \pi_{in}^{LC} \lambda_n^\sigma P_n^{LC^{1-\sigma}}$$

First order conditions from the producer's problem (Appendix D) imply optimal land allocation:

(11) $$Y_i^{EF} = \frac{r_i L_i^{EF}}{\alpha}$$

$$Y_i^{LC} = r_i L_i^{LC}$$

and land market clearing implies $L_i = L_i^{EF} + L_i^{LC}$. Finally, the value of environmental services is obtained from the EF producer's problem (Appendix D):

$$w_i H_i = \frac{1-\alpha}{\alpha} r_i L_i^{EF}$$

3. Model Parameterization

In this section, a strategy is outlined for parameterizing the model that would allow it to be utilized for policy simulation purposes. In order to solve for global equilibrium, values for several parameters are required. The parameters, their meanings and the source of their value are listed in table 1. Values for σ and θ can be obtained from the existing literature, while α can be set equal to one minus the OECD average labor share in value added from input-output tables in the *OECD-STAN Database* (OECD, 2013).

A process for obtaining values for the remaining parameters is now outlined. First, a method is described for estimating bilateral agricultural trade costs τ_{ni} using bilateral agricultural trade data. Second, it is shown how these estimates are used along with equilibrium conditions to obtain the parameter that describes average productivity T_i in the agricultural sector, following the methodology first used in Eaton and Kortum (2002). Third, several approaches are outlined to calibrating the remaining parameters unique to the current model.

Table 1: Model parameters, their meaning and step in which they are addressed

τ_{ni}	Bilateral agricultural trade costs	See Section 3.1
T_i	Mean parameter for the agricultural productivity distribution	See Section 3.2
θ	Dispersion parameter for the agricultural productivity distribution	Simonovska and Waugh (2011)
σ	Elasticity of substitution	Ruhl (2008)
α	Land's value-added share in organic agriculture production	OECD (2006)
ζ_{ni}	Organic labelling costs in market n in excess of exporter i's domestic labelling costs	See Section 3.3
ω_i	Consumer love of sustainability	See Section 3.3
λ_i	Lagrange multiplier	See Section 3.3

3.1. *Bilateral Trade Costs*

Bilateral trade costs in the agricultural sector can be estimated using the structural relationship that defines bilateral market share in LC products - equation (8). Following Reimer and Li (2010), (8) is defined as:

$$S_i = \ln(T_i) - \theta \ln(r_i)$$

Following Eaton and Kortum, Waugh (2010) and others, trade costs τ_{ni} are proxied by:

$$\ln(\tau_{ni}) = b_{ni} + l_{ni} + RTA_{ni} + \sum_r d_{r_{ni}} + ex_i + \xi_{ni}$$

where b_{ni} and l_{ni} are dummy variables indicating that country n and i share a common border and language, respectively; RTA_{ni} is a dummy variable indicating common membership in a regional trade area; $d_{r_{ni}}$ is the coefficient on a dummy variable equal to one if the two countries are in distance category $r \in [1,6]$; ex_i is a fixed effect capturing exporter i-specific trade costs and ξ_{ni} is an error term capturing unobservable bilateral trade costs. Using these definitions in equation (8) and taking the log of the ratio of bilateral trade share π_{ni}^{LC} to domestic market share π_{nn}^{LC} the gravity model-like expression is derived from which it is possible to obtain the parameter estimates to calculate trade costs and average productivity:

$$(12) \qquad \ln\left(\frac{\pi_{ni}^{LC}}{\pi_{nn}^{LC}}\right) = S_i - \theta\left(b_{ni} + l_{ni} + RTA_{ni} + \textstyle\sum_r d_{r_{ni}} + ex_i\right) - S_n$$

where S_i are captured with country fixed effects.

Market shares that make up the dependent variable (π_{ni}^{k}) can be calculated using bilateral trade and production data obtained from the Food and Agricultural Organization of the United Nations (FAO, 2013). Ideally, the dependent variable would be calculated using data on trade and production in agricultural products produced in a low cost manner. However, at present there are very little data that separates trade and production based on production method. Therefore, it is assumed that the majority of agricultural production uses low-cost technology and that the measurement error arising from including

EF products in the calculation of market share is not systematically related to productivity and trade costs. Dummy variables capturing trade costs are obtained from the CEPII gravity data set (Head, Mayer and Ries, 2010). Unobservable trade costs ξ_{ni} are calibrated by setting the observed ratio of market shares equal to the ratio implied by parameter estimates from equation (12).

3.2. *Average Productivity*

It is possible to obtain a value for each country's average productivity in the agricultural sector using the estimates of S_i. Notice:

$$\ln(T_i) = \theta \ln r_i - S_i$$

To isolate T_i an estimate of r_i can be derived using the equilibrium condition from the producer's problem:

$$Y_i^{LC} = r_i L_i^{LC}$$

Again, since information on land use or production by production process is unavailable, r_i can be set equal to each country's agricultural output per hectare of arable land using arable land data from the World Bank's *World Development Indicators* (World Bank, 2012).

3.3. *Eco-Labelling Parameters*

To obtain values for the remaining parameters the structural relationships defined by the model can be used with the estimates for trade costs and average productivity discussed above. To obtain a value for ζ_{ni}, the excess of exporter i's labelling costs in market n over those of domestic producers, the following relationship is used:

$$\frac{\pi_{ni}^{EF}}{\pi_{nn}^{EF}} = \frac{T_i\left(r_i^{\alpha} w_i^{1-\alpha} \tau_{ni} \zeta_{ni}\right)^{-\theta}}{T_n\left(r_n^{\alpha} w_n^{1-\alpha}\right)^{-\theta}}$$

Estimates of T_i, r_i and τ_{ni} are available from the previous step. With estimates of w_i and $\left(\pi_{ni}^{EF} / \pi_{nn}^{EF}\right)$, ζ_{ni} can be solved for. The U.S., Canada, the European Union (EU) and other countries have recently introduced HS codes for organic products, and many of these countries are likely to have information on the value of organic production. In future work *EF* products will be defined as organic products, and the set of countries will be limited to those that have enough information to calculate π_{ni}^{EF}. To obtain an estimate of w_i the following equilibrium relationship can be used:

$$w_i H_i = (1-\alpha) Y_i^{EF}$$

To solve for w_i from this expression, it is assumed $H_i = 1$ for all countries. This is reasonable if only wealthy countries are used in the model.

Next, to obtain a value of the parameter ω_i the following relationship is used:

$$\frac{X_i^{EF}}{X_i^{LC}} = \omega_i \left(\frac{P_i^{EF}}{P_i^{LC}} \right)^{1-\sigma}$$

The information necessary to calculate P_i^{EF} and P_i^{LC} being available from equation (10). Finally, an estimate of λ_i can be obtained as in Fieler (2011).

4. Consumer Gains from Trade and Eco-Labelling

Consumer gains from the introduction of eco-labels on imported products arise to the extent that they lower the price of EF products. Introducing eco-labels can be seen as a decrease in ζ_{ni} from infinity. Without eco-labelling and trade, the price of EF products is fully determined by domestic production costs:

$$P_n^{EF} = \gamma {\Phi_n^{EF}}^{-1/\theta} = \gamma T_n (\kappa r_n^{\alpha} w_n^{1-\alpha})$$

Introducing eco-labels for imported EF products provides consumers access to the lower prices associated with products for which its trading partners have a comparative advantage and P_n^{EF} becomes:

$$P_n^{EF} = \gamma \left(T_n (\kappa r_n^{\alpha} w_n^{1-\alpha})^{-\theta} + \sum_{l \neq n} T_l \left(\kappa r_l^{\alpha} w_l^{1-\alpha} \tau_{nl} \zeta_{nl} \right)^{-\theta} \right)^{-1/\theta}$$

Holding the price of land and environmental services constant, this is an unambiguous decline in P_n^{EF}. Moreover, since ζ_{nl} does not enter into P_n^{LC} (Equation 10), it is also a decline in the price of EF products relative to LC products. From equation (9), this implies an increase in the share of expenditure allocated to EF products. To see this, we rewrite (9) as:

$$\frac{X_i^{EF}}{X_i} = \frac{\omega_i \left(\frac{P_i^{EF}}{P_i^{LC}}\right)^{1-\sigma}}{1 + \omega_i \left(\frac{P_i^{EF}}{P_i^{LC}}\right)^{1-\sigma}}$$

where X_i is total expenditure. With $\sigma > 1$, falling prices of EF products increases their share in total expenditure. In general equilibrium, EF products will increase their share of country i consumers' budgets to the extent that their price falls more than LC prices, which will depend on the distribution of adjustments to land rent, as well as trade and labelling costs around the world.

With a fully parameterized model, consumer gains from eco-labelling can be estimated by approximating the utility obtained with and without imported EF products, holding expenditure fixed. That is we calculate:

$$CW_i = \left(\frac{X_i^{LC'}}{P_i^{LC'}} + \frac{\omega_i^{\frac{1}{\sigma}} X_i^{EF'}}{P_i^{EF'}}\right) - \left(\frac{X_i^{LC}}{P_i^{LC}} + \frac{\omega_i^{\frac{1}{\sigma}} X_i^{EF}}{P_i^{EF}}\right)$$

where $X_i^{LC'}/P_i^{LC'} + \omega_i^{\frac{1}{\sigma}} X_i^{EF'}/P_i^{EF'}$ is weighted real expenditure on agricultural products with the introduction of eco-labels on imported products, and total expenditure is constrained to equal expenditure without eco-labels on imports:

$$\frac{X_i^{LC'}}{P_i^{LC'}} + \frac{X_i^{EF'}}{P_i^{EF'}} = \frac{X_i^{LC}}{P_i^{LC}} + \frac{X_i^{EF}}{P_i^{EF}}$$

The magnitude of consumer gains from the introduction of eco-labelling with international trade will vary across countries depending on the value consumers place on environmentally-friendly production as well as the distribution of trade and labelling costs.

5. Environmental Gains from Eco-Labelling and Trade

The magnitude of environmental gains from eco-labelling depends crucially on the objective of the eco-label. Only cases in which the eco-label signifies that a particular production process was followed are considered here. The environmental benefits of using a given EF production process relative to the LC production process are rarely if ever easy to quantify on a large scale. The interaction of natural resources and agricultural inputs for the purpose of producing crops or animal products always has some environmental impact. Calculating the negative environmental cost associated with that interaction at a given place and time requires very specific criteria, and may yet be difficult or impossible to measure. Moreover, just as an identical input bundle will not produce the same output in Canada as it will in Spain, so the environmental impact from an identical production process will vary depending on the characteristics of the natural resource base across countries over time.

Since the environmental gains from a given production technology cannot be directly calculated without much more information than is generally available, as in Larson (2003) the environmental gains from eco-labelling and trade EW_i are measured as a function of the increase in the share of land allocated to EF production:

$$EW_i = f\left(\frac{L_i^{EF'} - L_i^{EF}}{L_i}\right)$$

To see how introducing trade in eco-labelled products provides environmental gains in the exporting country, equation (11) is used to show that the optimal allocation of land implies:

$$\text{(13)} \qquad \frac{L_i^{EF}}{L_i^{LC}} = \frac{\sum_n \pi_{ni}^{EF} X_n^{EF}}{\sum_n \pi_{ni}^{LC} (X - X_n^{EF})}$$

The numerator in equation (13) is the value of country i's total production of EF products – exports plus domestic production. As illustrated in Section 4, as ζ_{ni} falls from infinity, π_{ni}^{EF} rises under general circumstances. Thus the numerator of (13) increases with the introduction of eco-labels under general circumstances. The denominator is the total value of LC products production. Again, from Section 4, $(X_n - X_n^{EF})$ is expected to decrease with the introduction of eco-labelling on imports under general conditions. Given that land markets must clear, it can therefore be expected that the introduction of eco-labels with trade will increase the share of land allocated to EF products, thereby providing an environmental gain.

6. Alternative Eco-Labelling Policies

While measuring the absolute level of environmental gains from eco-labels and trade is complicated by the challenge of objectively measuring the relative environmental impact of two production processes, our model is able to offer valuable insights into the relative gains from eco-labelling and trade under various policies. Here the impact of two eco-labelling policy scenarios are examined when two separate economies choose to integrate: mutual recognition and regulatory harmonization.

Mutual recognition of eco-labels among countries implies that products meeting domestically sufficient criteria for an eco-label may be sold with that eco-label in an import market without meeting additional criteria or providing additional proof that domestically sufficient criteria have been met. For example, since 2012, the European Union and United States have had a mutual recognition agreement for organic products: products meeting the criteria for an organic label in the United States may be exported and labelled as organic in the European Union.

Under a policy of mutual recognition, labelling costs in the export market are identical to domestically sufficient labelling costs. That is, $\zeta_{ni} = \zeta_{in} = \zeta_{ii} = \zeta_{nn} = 1$ and mutual recognition lowers labelling costs in foreign markets from $\zeta_{ni}, \zeta_{in} > 1$. From equation (7) it is clear that, holding all prices and all other countries' labelling costs constant, lowering ζ_{ni} increases π_{ni}^{EF} – an increase in bilateral trade in eco-labelled products.

The extent to which mutual recognition provides consumer and environmental gains will depend on its effects on the prices of EF and LC products. Holding the prices of land and environmental services constant, mutual recognition unambiguously lowers both, the absolute price of EF products as well as the price of EF relative to LC products. To see this, suppose there is mutual recognition of eco-labels in countries n and i. Then, the price of EF products in market n becomes:

$$P_n^{EF} = \gamma \Phi_n^{EF^{-\frac{1}{\theta}}} = \gamma \left(T_n (\kappa r_n^\alpha w_n^{1-\alpha})^{-\theta} + T_i \big(\kappa r_i^\alpha w_i^{1-\alpha} \tau_{ni}\big)^{-\theta} + \sum_{l \neq n,i} T_l \big(\kappa r_l^\alpha w_l^{1-\alpha} \tau_{nl} \zeta_{nl}\big)^{-\theta} \right)^{-1/\theta}$$

The first term in parentheses is the contribution of domestic prices, which is unchanged under mutual recognition. The second term is country i's contribution, which has increased from $T_i\big(\kappa r_i^\alpha w_i^{1-\alpha}\tau_{ni}\zeta_{ni}\big)^{-\theta}$, lowering P_n^{EF}. The contribution of all other countries is unchanged. Since P_n^{LC} is not a function of ζ_{ni} it is unchanged. Thus from equation (9), with $\sigma > 1$ the share of expenditure allocated to EF prices rises with mutual recognition. From section 4, it is known that this implies an increase in consumer welfare in both countries. From section 5, it also known that increased expenditure on EF products and increased bilateral trade in EF products generates environmental gains in both countries as the expanded export opportunity increases the share of land allocated to EF production.

Under a policy of regulatory harmonization, eco-labelling criteria is standardized across countries. Thus, as with mutual recognition, labelling costs are constant in the domestic and foreign market. However, the cost of meeting agreed labelling criteria may differ from the cost of meeting domestically sufficient criteria. Let ζ_n' be the cost of meeting mutually agreed criteria in excess of domestically sufficient criteria. Now:

$$P_n^{EF} = \gamma \left(T_n (\kappa r_n^\alpha w_n^{1-\alpha} \zeta_n{}')^{-\theta} + T_i \big(\kappa r_i^\alpha w_i^{1-\alpha} \tau_{ni} \zeta_i'\big)^{-\theta} + \sum_{l \neq n,i} T_l \big(\kappa r_l^\alpha w_l^{1-\alpha} \tau_{ni} \zeta_{ni}\big)^{-\theta} \right)^{-1/\theta}$$

The first term in parentheses is again the contribution of domestic prices, which has fallen from $T_n(\kappa r_n^\alpha w_n^{1-\alpha})^{-\theta}$, increasing P_n^{EF}. The second term reflects country i's contribution, which may be larger or smaller depending on whether ζ_i' is larger or smaller than ζ_{ni}. In this case the price of EF products may rise or fall, depending on the magnitudes of ζ_n' and ζ_i'. From section 4 it is known that if the prices of EF products rise, their share in total expenditure will fall, reducing consumer welfare.

If mutually agreed criteria are more costly and not accompanied by sufficiently larger environmental benefits, such an effort may reduce environmental welfare. To see this, observe that with $\zeta_n' > 1$ domestic market share falls under mutual recognition:

$$\pi_{nn}^{EF} = \frac{T_n(\kappa r_n^{\alpha} w_n^{1-\alpha}\zeta_n')^{-\theta}}{\Phi_N^{EF}} < \frac{T_n(\kappa r_n^{\alpha} w_n^{1-\alpha})^{-\theta}}{\Phi_N^{EF}}$$

If this is manifest as a decline in production for the domestic market that is not offset by an increase in exports to market i, equation (13) implies that the share of land allocated to EF production in country n will decline, resulting in an environmental loss.

7. Summary and Conclusions

The key motivation for this paper is that consumers are increasingly demanding food characterized by credence attributes such as environmentally-friendly production methods, where eco-labelling and certification of any environmental claims are critical in resolving the associated informational asymmetry. Importantly, trade in such products may actually generate environmental gains. In this context, a Ricardian-type trade model was used to explore the potential gains to consumers and the environment of increased trade in and eco-labelling of environmentally-friendly food and agricultural products, as well as compare the alternatives of mutual recognition versus harmonization of different countries' eco-labelling regimes.

The analysis presented in the paper generates three key results: first, with eco-labelling, the price of environmentally-friendly products falls, thereby generating benefits to consumers; second, introduction of eco-labelling increases the share of land allocated to environmentally-friendly products with associated environmental benefits; and third, in terms of choice of eco-labelling regime, a policy of mutual recognition will increase trade in eco-labelled products, resulting in gains to both consumers and the environment, while regulatory harmonization may result in an environmental loss, depending on the cost of harmonized eco-labelling relative to any environmental benefits. Ultimately, the extent which trade in eco-labelled products benefits consumers and the environment is an empirical issue. Therefore, calibrating the current model along the lines suggested in the paper, and using it to conduct relevant policy simulations will be the next step in this line of research.

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Figure 1: Comparative Advantage along the Continuum

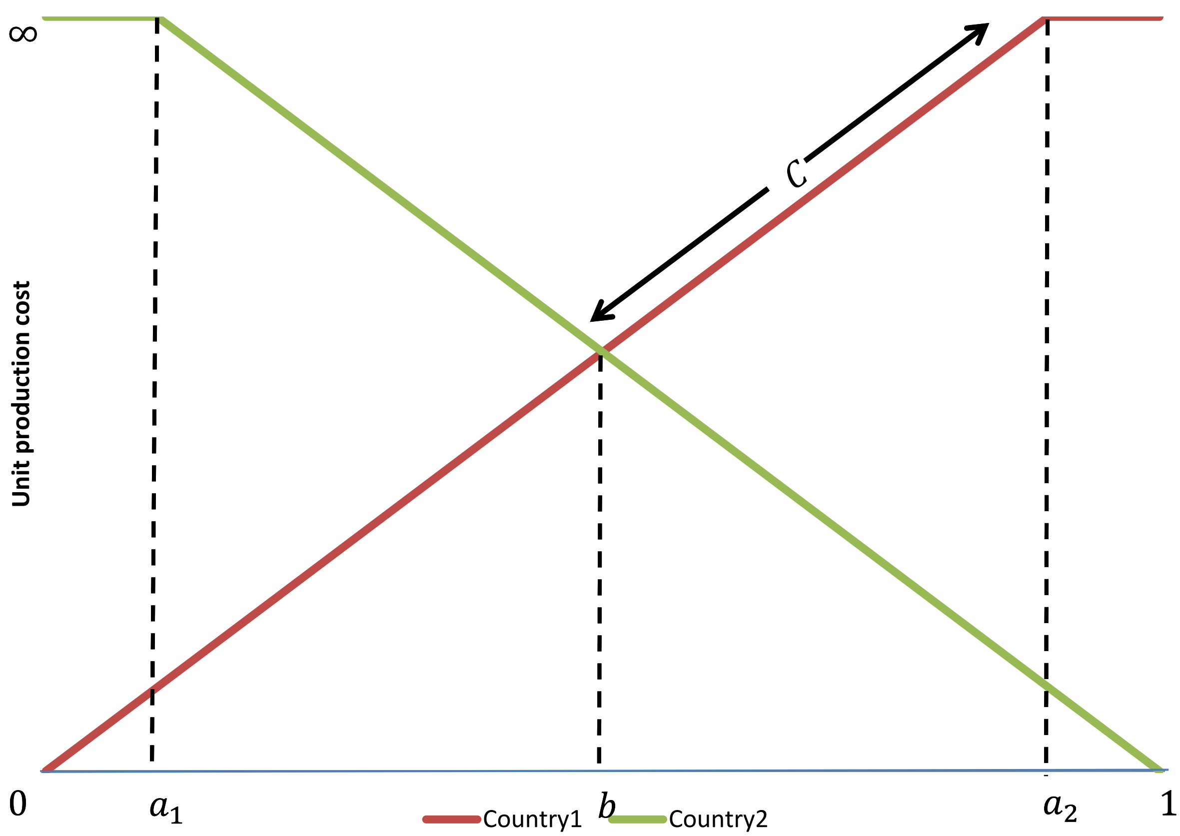
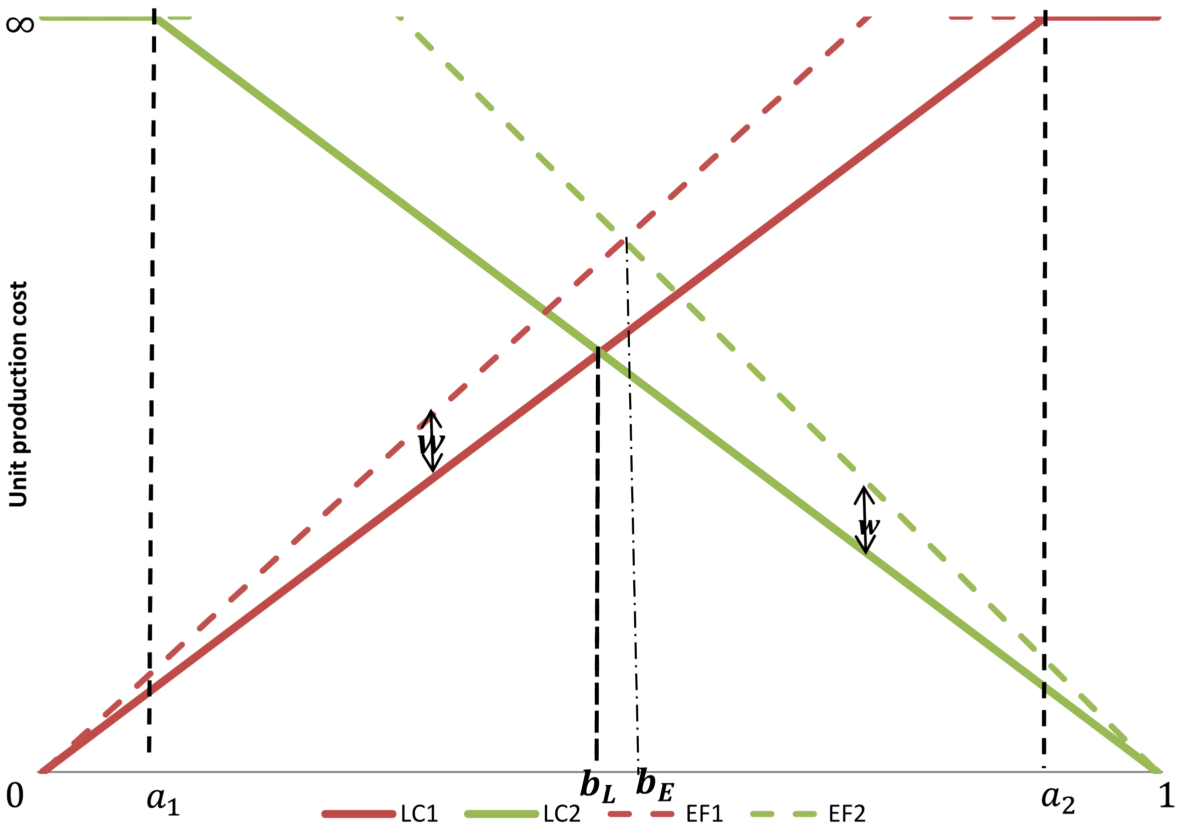


Figure 2: Comparative Advantage along the Continuum



Appendices

Appendix A

Since perfect competition is assumed, price is equal to unit cost. Producers of the *EF* good choose land and environmental inputs to solve:

$$\min r_i L_i + w_i H_i$$

$$s.t.\, q_i(j) = z_i(j) L_i^{\alpha} H_i^{1-\alpha}$$

From the constraint:

$$L_i = \left(\frac{q_i(j)}{z_i(j) H_i^{1-\alpha}}\right)^{\frac{1}{\alpha}}$$

So the problem can be re-written:

$$\min r_i \left(\frac{q_i(j)}{z_i(j)}\right)^{\frac{1}{\alpha}} H_i^{\frac{\alpha-1}{\alpha}} + w_i H_i$$

FOC:

$$\left(\frac{1-\alpha}{\alpha}\right) r_i \left(\frac{q_i(j)}{z_i(j)}\right)^{\frac{1}{\alpha}} H_i^{\frac{-1}{\alpha}} = w_i$$

Therefore:

$$H_i^* = \left(\frac{w_i}{r_i}\right)^{-\alpha} \left(\frac{\alpha}{1-\alpha}\right)^{-\alpha} \left(\frac{q_i(j)}{z_i(j)}\right)$$

and:

$$L_i^* = \left(\frac{w_i}{r_i}\right)^{1-\alpha} \left(\left(\frac{\alpha}{1-\alpha}\right)\right)^{1-\alpha} \left(\frac{q_i(j)}{z_i(j)}\right)$$

Therefore, to produce quantity Q costs:

$$r_i L_i^* + w_i H_i^* = \kappa \frac{r_i^{\alpha} {w_i}^{1-\alpha}}{z_i(j)} Q$$

where $\kappa = \left(\frac{1}{1-\alpha}\right)\left(\frac{\alpha}{1-\alpha}\right)^{-\alpha}$. Set $Q = 1$ and you have the unit cost function. To obtain unit costs for the *LC* good, simply set $\alpha = 1$.

Appendix B

The ratio of expenditure on each type of product is derived from the consumer's problem as follows. For a given level of utility $\overline{U}$, consumers choose $q_i^{LC}(j)$ and $q_i^{EF}(j)$ for each product j by solving:

$$\min \int_0^1 p_n^{LC}(j) q_n^{LC}(j) dj + \int_0^1 p_n^{EF}(j) q_n^{EF}(j) dj$$

$$s.t. \overline{U} = \frac{\sigma}{\sigma - 1}\left(\int_0^1 q_i^{LC}(j)^{\frac{\sigma-1}{\sigma}} dj + \omega_i^{1/\sigma} \int_0^1 q_i^{EF}(j)^{\frac{\sigma-1}{\sigma}} dj\right)$$

First order conditions with respect to $q_i^{EF}(l)$ for some product l:

$$p_i^{EF}(l) = \lambda \omega_i^{\frac{1}{\sigma}} q_i^{EF}(l)^{\frac{-1}{\sigma}}$$

Rearranging this yields:

$$q_i^{EF}(l) = \left(\frac{p_i^{EF}(l)}{\lambda \omega_i^{\frac{1}{\sigma}}}\right)^{-\sigma}$$

Multiplying both size by $p_i^{EF}(l)$, total expenditure on product l is:

$$p_i^{EF}(l) q_i^{EF}(l) = p_i^{EF}(l)^{1-\sigma} \lambda^{\sigma}\, \omega_i$$

Integrating over all products, total expenditure on EF products is:

$$\int_0^1 p_i^{EF}(j) q_i^{EF}(j)\, dj \equiv X_i^{EF} = \lambda^{\sigma}\, \omega_i {P_i^{EF}}^{1-\sigma}$$

Where P_i^{EF} is a price index for EF products, which is derive in Appendix C.

Likewise, total expenditure on LC products is

$$X_i^{LC} = \lambda^{\sigma}\, {P_i^{LC}}^{1-\sigma}$$

Thus, the ratio of expenditure on EF to LC products is:

$$\frac{X_i^{EF}}{X_i^{LC}} = \omega_i \left(\frac{P_i^{EF}}{P_i^{LC}}\right)^{1-\sigma}$$

Appendix C

Here the price indices for each type of product are derived. Buyers aggregate EF products with constant elasticity σ. As such, for a given $\bar{Q}^{EF}$ they solve the problem:

$$\min_{q_i^{EF}(j)} \int_0^1 p_i^{EF}(j) q_i^{EF}(j)\, dj$$

$$s.t. \quad \bar{Q}^{EF} = \int_0^1 q_i^{EF}(j)^{\frac{\sigma-1}{\sigma}} dj$$

First order conditions for product l give:

$$p_i^{EF}(l) = \lambda \omega_i^{\frac{1}{\sigma}} q_i^{EF}(l)^{\frac{-1}{\sigma}}$$

The ratio of first order conditions for products l and k is thus:

$$\frac{p_i^{EF}(l)}{p_i^{EF}(k)} = \frac{q_i^{EF}(l)^{\frac{-1}{\sigma}}}{q_i^{EF}(k)^{\frac{-1}{\sigma}}}$$

Rearranging:

$$q_i^{EF}(l) = q_i^{EF}(k) \left(\frac{p_i^{EF}(l)}{p_i^{EF}(k)} \right)^{-\sigma}$$

Placing this in the constraint:

$$\bar{Q}^{EF} = \frac{q_i^{EF}(k)^{\frac{\sigma-1}{\sigma}}}{p_i^{EF}(k)^{1-\sigma}} \int_0^1 \left(p_i^{EF}(j)^{1-\sigma} \right) dj$$

Rearranging:

$$q_i^{EF}(k) = \frac{p_i^{EF}(k)^{-\sigma}}{\int_0^1 \left(p_i^{EF}(j)^{1-\sigma} \right) dj^{\frac{\sigma}{\sigma-1}}} \bar{Q}^{EF \frac{\sigma}{\sigma-1}}$$

Multiplying by $p_i^{EK}(k)$ gives us expenditure on product k. Integrating over all EF products gives total expenditure on $\bar{Q}^{EF}$ EF products:

$$\int_0^1 p_i^{EF}(j) q_i^{EF}(j)\, dj = \int_0^1 \frac{p_i^{EF}(j)^{1-\sigma}}{\int_0^1 \left(p_i^{EF}(j)^{1-\sigma} \right) dj^{\frac{\sigma}{\sigma-1}}} dj \bar{Q}^{EF \frac{\sigma}{\sigma-1}}$$

$$= \int_0^1 \left(p_i^{EF}(j)^{1-\sigma} \right) dj^{\frac{1}{1-\sigma}} \bar{Q}^{EF \frac{\sigma}{\sigma-1}}$$

Let $\bar{Q}^{EF} = 1$ and the unit price index:

$$P_i^{EF} = \int_0^1 \left(p_i^{EF}(j)^{1-\sigma}\right) dj^{\frac{1}{1-\sigma}} \quad (i)$$

Now it is shown that $P_i^{EF} = \gamma \phi_i^{EF^{\frac{1}{\theta}}}$. Equation (i) can be rewritten:

$$P_i^{EF} = \left(\int_0^\infty {p_i}^{1-\sigma} dG_i^{EF}(p) dp\right)^{\frac{1}{1-\sigma}} \quad (ii)$$

By definition:

$$dG_i^{EF}(p) = \Phi_i^{EF} p^{\theta-1} \exp\{-\Phi_i^{EF} p^\theta\}$$

Using this in (ii):

$$P_i^{EF} = \left(\int_0^\infty {p_i}^{1-\sigma} \Phi_i^{EF} p^{\theta-1} \exp\{-\Phi_i^{EF} p^\theta\}\, dp\right)^{\frac{1}{1-\sigma}}$$

Let $x = \Phi_i^{EF} p^\theta$. Then $dx = \Phi_i^{EF} \theta p^{\theta-1}$ and $p = \left(\frac{x}{\Phi_i^{EF}}\right)^{\frac{1}{\theta}} \Rightarrow p^{1-\sigma} = \left(\frac{x}{\Phi_i^{EF}}\right)^{\frac{1-\sigma}{\theta}}$. Then:

$$P_i^{EF^{1-\sigma}} = \int_0^\infty \left(\frac{x}{\Phi_i^{EF}}\right)^{\frac{1-\sigma}{\theta}} \Phi_i^{EF} p^{\theta-1} \exp\{-x\}\, dp = \Phi_i^{EF^{\frac{\sigma-1}{\theta}}} \Gamma\left(\frac{\theta+1-\sigma}{\theta}\right)$$

$$\Rightarrow P_i^{EF} = \Phi_i^{EF^{-1/\theta}} \Gamma\left(\frac{\theta+1-\sigma}{\theta}\right)$$

It is straightforward to show likewise that:

$$P_i^{LC} = \Phi_i^{LC^{-1/\theta}} \Gamma\left(\frac{\theta+1-\sigma}{\theta}\right)$$

Appendix D

Resource allocation across product types solves:

$$\max_{H_i, L_i^{LC}, L_i^{EF}} w_i H_i + r_i L_i^{LC} + r_i L_i^{EF}$$

$$s.t.\, Y_i = \int z_i(j) L_i dj + \int z_i(j) L_i^{\alpha} H_i^{1-\alpha} dj$$

$$\mathcal{L} = w_i H_i + r_i L_i^{LC} + r_i L_i^{EF} + \lambda\left(Y_i - \int z_i(j) L_i dj - \int z_i(j) L_i^{\alpha} H_i^{1-\alpha} dj\right)$$

First order conditions:

(D1) $$w_i = \frac{\lambda(1-\alpha)}{H_i} Y_i^{EF}$$

(D2) $$r_i = \frac{\lambda}{L_i^{LC}} Y_i^{LC}$$

(D3) $$r_i = \frac{\lambda\alpha}{L_i^{EF}} Y_i^{EF}$$

From (D1) and (D2):

(D4) $$w_i H_i = \frac{1-\alpha}{\alpha} r_i L_i^{EF}$$

From (D2) and (D3):

(D5) $$r_i L_i^{LC} = \frac{1}{\alpha} \frac{Y_i^{LC}}{Y_i^{EF}} r_i L_i^{EF}$$

Using (D5) in the objective function:

$$Y_i = \frac{1-\alpha}{\alpha} r_i L_i^{EF} + r_i L_i^{EF} + \frac{1}{\alpha} \frac{Y_i^{LC}}{Y_i^{EF}} r_i L_i^{EF}$$

$$= r_i L_i^{EF} \left(\frac{1-\alpha}{\alpha} + 1 + \frac{1}{\alpha} \frac{Y_i^{LC}}{Y_i^{EF}} \right)$$

$$= r_i L_i^{EF} \left(\frac{1}{\alpha} + \frac{1}{\alpha} \frac{Y_i^{LC}}{Y_i^{EF}} \right)$$

$$= r_i L_i^{EF} \left(\frac{1}{\alpha} \left(1 + \frac{Y_i^{LC}}{Y_i^{EF}} \right) \right)$$

$$= r_i L_i^{EF} \frac{Y_i}{\alpha Y_i^{EF}}$$

$$\Rightarrow \alpha Y_i^{EF} = r_i L_i^{EF}$$