The International Agri-Food Trade Network (IAFTN) Model

Technical Report

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Introduction

Trade models typically used to provide assessments of agricultural and food policy reforms (such as the partial and general equilibrium modelling frameworks) are characterised by a number of key assumptions that often do not reflect important dimensions of agricultural and food chains across and between most countries (Devadoss et al, 1993; Soregaroli et al., 2011). The International Agri-Food Trade Network (IAFTN) model has been developed to accommodate, in a manageable way, several features of markets and trade that have already been identified in published and peer-reviewed work, such as:

- international trade architecture,
- imperfect competition in markets for both farm production (buyer power) and finished food goods (seller power),
- intermediaries in supply chains and their market power,
- intra-industry trade,
- product differentiation,
- asymmetry in market sizes,
- asymmetry in farmers productivity, and
- government policy biases.

When all of these features exist in a determined market, countries become highly connected in the sense that actions taken by a particular country (e.g. signing a trade agreement, adoption of a domestic policy, etc.) affects other countries. The intensity of the interaction depends very much on a) the degree of market power, and b) the international trade architecture.

Where buyer's power applies, intermediary firms (such as processors and supermarkets) face an increasing marginal cost to their input products, implying that an increase in the demand for an agricultural product from the farming sector will push the price paid to this sector up negatively (for the intermediaries), affecting the profits made by these firms. To counteract this, the intermediaries adjust by decreasing the product output sold in domestic and foreign markets where they compete under oligopoly. As a result, competitor countries operating in the same markets will be affected and it will be transmitted to other countries in the network. One of the key features of the IAFTN is that it considers the important role of intermediaries in terms of creating interdependency between countries as a consequence of market power. This role is largely ignored by other modelling approaches.

The IAFTN captures these effects, making this model unique. In contrast, alternative models, cannot capture these effects because, by the definition of perfect competition, countries are assumed to be price takers. Therefore, such models assume that there will be no flow-on effects in other countries

The aim of this technical report is to explain how the model was developed and the main assumptions considered in its design. For this purpose, the key features of the model outlined above are explained as follows.

The Network Architecture

International trade can be represented in different ways. A useful representation is by means of networks, in which countries are represented as nodes and links exist as international agreements between countries. This representation is useful because it shows the possible direct and indirect relevant transmission channels between countries when markets operate under imperfect competition, being one of the main features considered by the IAFTN.

Given the intricate and complex network of international trade agreements across the real world (see Figure 1), it is not possible to develop a manageable modelling approach that considers all the possible interactions. The associated mathematical complexity is a well-known limitation expressed by theoretical economists working in the area of networks (See for example Goyal, 2015).

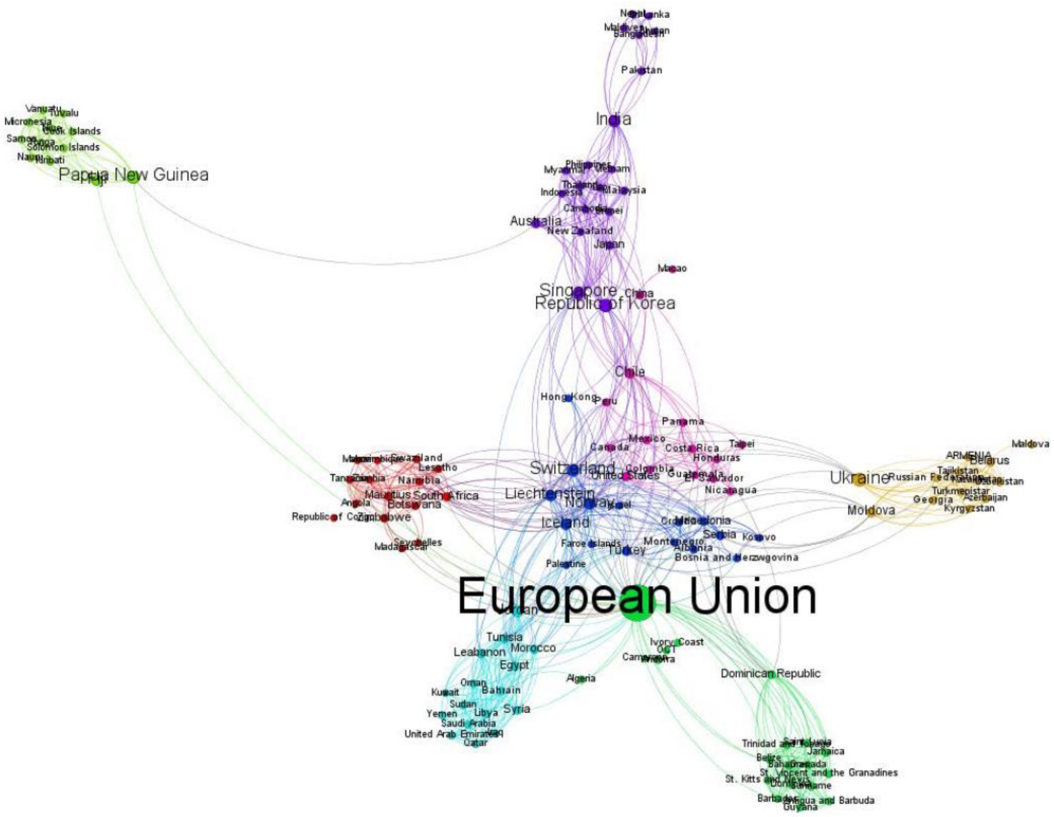

Figure 1. International Trade Agreements Network

In order to address this mathematical complexity of real world agreements, the IAFTN considers a world composed of four nodes (some of which can be an aggregation of countries when it is appropriate to do so) which represent the most relevant for the country under study. With four country nodes, the IAFTN considers the 64 possible network combinations that can be formed between these countries (see Figure 2). From these possible networks, researchers select a) one that represents the current trade structure for a determined agricultural commodity/food good, and b) one that will emerge after an agreement is signed.

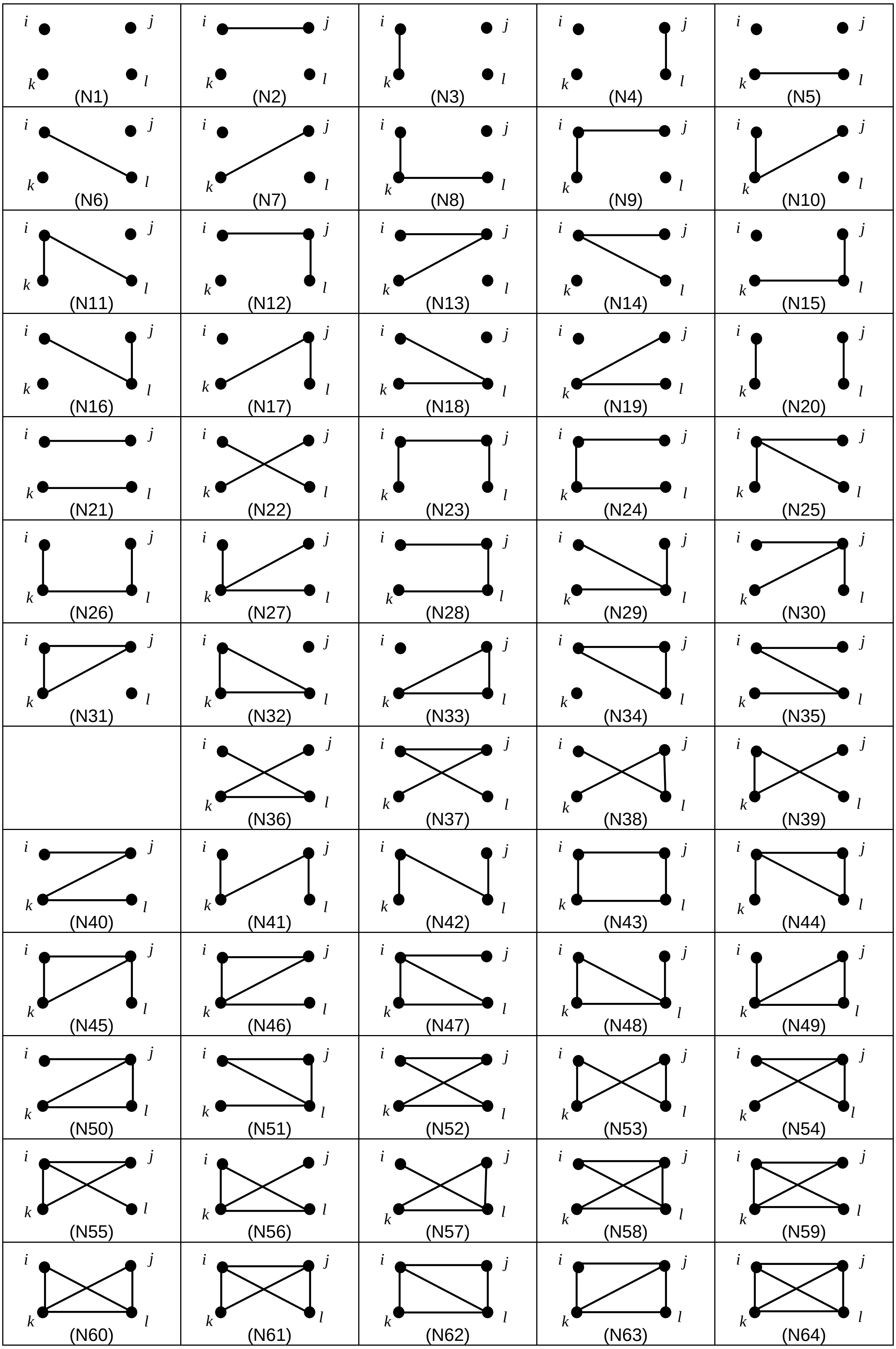

Figure 2. Possible international trade networks that can be formed with four counties.

Using the simulated data obtained in both networks (a and b) they are compared to predict a number of key indicators such as the marginal change in the level of exports, imports and prices in each country. The predicted information is obtained following calibration of the model, and after the data are triangulated with real data.

Formally, the network architecture considered by the IAFTN is described as follows:

An international agreement between countries *i* and *j* is described by a link, given by a binary variable $g_{ij} \in \{0,1\}$. If $g_{ij} = 0$, then no agreement exists between the countries *i* and *j*. If $g_{ij} = 1$, then an agreement exists between them. A network $g \in \{(g_{ij})_{ij \in \mathrm{N}}\}$ is a description of the international agreements that exist between the countries in N, where N = {1, 2,..., *N*} is the set of countries, and *N* is the total number of countries, currently a maximum of four. Network g^c is the complete network ($g_{ij} = 1\ \forall\ i,j \in \mathrm{N}$) and corresponds to global free trade, and Network g^e is the empty network ($g_{ij} = 0\ \forall\ i,j \in \mathrm{N}$) and corresponds to a network in which all countries do not have an agreement. Let *G* denote the set of all possible networks of international agreements between countries. Let $Ni(g) = \{j\ \forall\ \mathrm{N}: g_{ij} = 1\}$ be the set of countries with whom country *i* has an international trade agreement in network *g*. When $g_{ii} = 1$, we assume that $i \in N_i(g)$ and the cardinality of $Ni(g)$ is denoted by $n_i(g)$. Let $L_i(g) = \{(g_{ij})_{ij \in \mathrm{N}} : j \in N_i(g)\}$ be the set of links existing in country *i* in network *g*. Finally, let $W_i(g)$, $CS_i(g)$, $\pi_i(g)$ and $TR_i(g)$ be welfare, consumer surplus, total profit and tariff revenue, respectively, in country *i* and in network *g*.

The model

The IAFTN model is an extension of the network models developed by Goyal and Joshi (2006) and Furusawa and Konishi (2007). It assumes the existence of intermediaries in each country. These firms are assumed to have buyer power in the inter-play between farmers and intermediaries and with seller power at the consumer end through trade. The model also allows for asymmetry in market size and fixed cost.

In this model, it is assumed that the farming sector is formed of a single group of farmers who are price takers (i.e. farmers are highly atomized) and produce a homogeneous good denoted by $q_i^f(g)$ (i.e. this is the total output produced by the farmers in country *i* and in network *g*). It is assumed that this output is the input purchased by the domestic intermediaries. Since the latter are few buyers of this input, these firms face a non-horizontal inverse supply function of the homogeneous product (White, 1996):

$$P_i^f(g) = \gamma_i + \theta Q_i^f(g) \tag{1}$$

where $p_i^f(g)$ is the price of the homogeneous good that is paid to farmers, γ_i is a constant (it becomes the fixed cost faced by the intermediaries of country *i*); θ is the slope of inverse supply function of the farming sector); and $Q_i^f(g)$ is the total output sold by the farming sector of country *i*. This means:

$$Q_i^f(g) = n_i^i q_i^i(g) + n_i^i q_j^i(g) + n_i^i q_k^i(g) + n_i^i q_l^i(g) \quad (2)$$

where *i*, *j*, *k* and *l* are the four countries in the network, and n_i^i is the number of intermediaries in country *i*. For further analysis we define (see Expressions 12 and 14 below):

$$Q_i^f(g) = Q_{i-j}^f(g) + n_i^i q_j^i(g) \quad (3)$$

Note that the coefficient θ reflects the additional mechanism that plays a key role in explaining the stability of agricultural trade networks, which is the increasing marginal cost to free trade faced by the intermediaries.

On the other hand, it is assumed that the output sold in the domestic market and imported output are differentiated. This is captured by the following demand functions for these outputs, respectively (see Dixit, 1979):

$$P_i^i(g) = \alpha_i^i - \beta_i^i Q_i^i(g) - kQ_i^{-i}(g) \quad (4)$$

$$P_i^{-i}(g) = \alpha_i^{-i} - \beta_i^{-i} Q_i^{-i}(g) - kQ_i^i(g) \quad (5)$$

where $P_i^i(g)$ is the price paid for the domestic output in country *i*; $P_i^{-i}(g)$ is the price paid for imported output in country *i*; α_i^i is interpreted as the market size of the domestic output in country *i* (Goyal and Joshi, 2006); α_i^{-i} is the market size of the imported goods in country *i*; β_i^i is the slope of the inverse demand for the domestic output in country *i*; β_i^{-i} is the slope of the inverse demand for the imported goods in country *i*; and k is a parameter reflecting good differentiation. In these equations:

$$Q_i^i(g) = n_i^i q_i^i(g) \quad (6)$$

$$Q_i^{-i}(g) = Q_i^j(g) + Q_i^k(g) + Q_i^l(g) = n_j^j q_i^j(g) + n_k^k q_i^k(g) + n_l^l q_i^l(g) \quad (7)$$

where n_i^i, n_j^j, n_k^k and n_l^l are the number of homogeneous intermediaries in countries *i*, *j*, *k* and *l*, respectively.

In relation to the intermediaries, they are assumed to compete Cournot oligopoly in the markets where they sell their output. The optimization problem would depend on whether the target market belong to a country having or not an agreement. If countries *i* and *j* have an agreement, then:

$$\pi_i^{j(1)}(g) = q_i^j(g)\left[P_i^{-i}(g) - P_j^f(g)\right] \tag{8}$$

where $\pi_i^{j(1)}(g)$ is the profit made by a particular intermediary (i.e. intermediary 1) of country *j* in country *i*. The first order condition of this expression is:

$$\frac{\partial \pi_i^{j(1)}(g)}{\partial q_i^j(g)} = P_i^{-i}(g) - P_j^f(g) + \left[\frac{\partial P_i^{-i}(g)}{\partial q_i^j(g)} - \frac{\partial P_j^f(g)}{\partial q_i^j(g)}\right] q_i^j(g) \tag{9}$$

Using the derivatives of $P_i^{-i}(g)$ and $P_j^f(g)$:

$$\frac{\partial \pi_i^{j(1)}(g)}{\partial q_i^j(g)} = P_i^{-i}(g) - P_j^f(g) - \left(\beta_i^{-i} + \theta\right) q_i^j(g) \tag{10}$$

Substituting $P_i^{-i}(g)$ and $P_j^f(g)$:

$$q_i^j(g) = \frac{\alpha_i^{-i} - \gamma_j - \beta_i^{-i}\left(n_k^k q_i^k(g) + n_l^l q_i^l(g)\right) - k n_i^i q_i^i(g) - \theta Q_{j-i}^f(g)}{\left(\beta_i^{-i} + \theta\right)\left(n_i^i + 1\right)} \tag{11}$$

This is the optimal output sold by a single intermediary in country *j*. Aggregating by the number of intermediaries in this country:

$$Q_i^j(g) = n_j^j q_i^j(g) = n_j \left[\frac{\alpha_i^{-i} - \gamma_j - \beta_i^{-i}\left(n_k^k q_i^k(g) + n_l^l q_i^l(g)\right) - k n_i^i q_i^i(g) - \theta Q_{j-i}^f(g)}{\left(\beta_i^{-i} + \theta\right)\left(n_j^j + 1\right)}\right] \tag{12}$$

On the other hand, the profit made by a determined intermediary of country *k* in country *i* when these countries do not have an agreement is:

$$\pi_i^{k(1)}(g) = q_i^k(g)\left[P_i^{-i}(g) - P_k^f(g) - T_k^i(g)\right] \tag{13}$$

Where $T_k^i(g)$ is the tariff applied by country *i* to country *k* in network *g*. Using a similar approach considered by the previous profit analysis, it is concluded that the optimal output sold by the intermediaries of country *k* to country *i* is:

$$Q_i^k(g) = n_k^k q_i^k(g) = n_k^k \left[\frac{\alpha_i^{-i} - \gamma_k - T_k^i(g) - \beta_i^{-i}\left(n_j^j q_i^j(g) + n_l^l q_i^l(g)\right) - k n_i^i q_i^i(g) - \theta Q_{k-i}^f(g)}{(\beta_i^{-i} + \theta)(n_k^k + 1)} \right] \quad (14)$$

Finally, governments are assumed to maximise the following weighted welfare function:

$$W_i(g) = a_i CS_i(g) + b_i \pi_i(g) + c_i PS_i(g) + d_i TR_i(g) \quad (15)$$

where $CS_i(g)$ corresponds to consumer surplus in country *i*; $\pi_i(g)$ is the total profit made by the intermediaries of this country, $PS_i(g)$ is the producer surplus of the farming sector in country *i*; $TR_i(g)$ is tariff revenue; and a_i, b_i, c_i, and d_i are the weights (between 0 and 1) placed by the government of country *i* on the components of the welfare function. Biased governments are captured by these parameters. Expressions for $CS_i(g)$, $\pi_i(g)$, $PS_i(g)$ and $TR_i(g)$ are obtained using the optimal output in Expressions 12 and 14:

$$CS_i(g) = \frac{\beta_i^i Q_i^{i2}(g) + \beta_i^{-i}\left(Q_i^j(g) + Q_i^k(g) + Q_i^l(g)\right)^2 + 2kQ_i^i(g)\left(Q_i^j(g) + Q_i^k(g) + Q_i^l(g)\right)}{2} \quad (16)$$

$$\pi_i(g) = \sum_{j \in N_i(g)} n_i^i \pi_i^i(g) + \sum_{k\text{Ï}N_i(g)} n_k^k \pi_i^k(g) = \sum_{j \in N_i(g)} \frac{\left(\beta_i^i + \theta\right)}{n_i^i} Q_i^{i2}(g) + \sum_{k \notin N_i(g)} \frac{\left(\beta_i^{-i} + \theta\right)}{n_k^k} Q_i^{k2}(g) \quad (17)$$

$$PS_i(g) = \frac{\theta}{2} Q_i^{f2}(g) = \frac{\theta}{2}\left(Q_i^i(g) + Q_j^i(g) + Q_k^i(g) + Q_l^i(g)\right)^2 \quad (18)$$

$$TR_i(g) = \sum\nolimits_{k\text{Ï}N_i(g)} T_k^i(g) Q_i^k(g) \quad (19)$$

Using these expression, optimal tariffs are calculated in each country in a determined network. These tariffs are then employed to get values for outputs, prices and the components of the welfare function. Numerical estimations are obtained when adopting specific values of the parameters used in the model. Some of them are estimated, others are obtained from previous investigations, and other by means such as consultation with experts.

Summary

The IAFTN model offers the flexibility to incorporate the important aspects of the food sector that characterise both the UK and its major (potential) trading partners in the assessment of future UK trade agreements. The IAFTN modelling approach considers a number of features that are present in the agri-food sector (e.g. intermediaries with market power in the supply chain, intra-industry trade, policy biases, and famers asymmetry in productivity, among others).

This makes the IAFTN model unique and different from other existing approaches that are based on the standard assumption of perfect competition. This allows the IAFTN far more flexibility in terms of the ability to predict trade outcomes and to assess these predictions under different scenarios and consider the real and different features of a sector.

In addition, the IAFTN can not only make predictions that are much more closely aligned with the current market structure of the agri-food sector, but it can also assess the stability of a new bilateral agreement, and possible posterior trade evolution paths.

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