The International Agri-Food Trade Network (IAFTN) Model

Technical Report UK/NZ Free Trade Deal

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1. Introduction

The objective of this document is to inform technical aspects of the modelling approach adopted to assess possible impacts of the UK/NZ deal on the UK agricultural sector for selected goods. For this purpose, the document is organised as follows:

Section 2 contains a general description of the characteristics of the model, referred to as the International Agri-Food Trade Network (IAFTN) model.

Section 3 shows the main equations considered in the model.

Section 4 explains the extensions that have been included since the previous UK/Australia deal simulation.

Section 5 describes the calibration process and the assumptions adopted in this process. A description of the database employed is also included.

Section 6 provides a summary.

2. The International Agri-Food Trade Network (IAFTN) model: general aspects

The IAFTN is a partial equilibrium model that assumes that markets operate under imperfect competition. It is an extension of the works developed by Goyal and Joshi (2006) and Furusawa and Konishi (2007) which 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

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.) affect other countries. The intensity of the interaction depends very much on:

a) the degree of market power
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. This implies that that there will be a rise in farm level prices, which will impact on intermediaries' profits. However, the rise is magnified since it is the marginal outlay curve that determines the increase which has a greater impact on costs as opposed to the case where the intermediary sector was competitive. 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.

In this approach, international trade is represented as a network, 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. This is one of the main features considered by the IAFTN.

One of the main disadvantages of the IAFTN is its complexity. The associated mathematical complexity is a well-known limitation expressed by theoretical economists working in the area of networks (see for example Goyal, 2015). In order to address this complexity of real-world agreements, the IAFTN considers a world composed of five 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 five country nodes, the IAFTN can provide reasonable trade simulations for the countries that are included in the network.

The simulations are carried out by comparing two networks that are quantified by the IAFTN: a network representing the actual pre-deal situation and a network representing the post-deal scenario. Using the simulated data obtained in both networks, 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 is triangulated with real data.

3. Mathematical description of the IAFTN

The IAFTN is based on two main considerations: network architecture and market structure. The network architecture provides the benchmark to assess any economic change. This is a relevant aspect of the model because research on network economics has found that agents' economic behaviour (i.e. the behaviour of nodes) is influenced by the network architecture. This means that predictions from the model are contingent to the network representation, and this is why a careful selection of a network architecture representation for the pre-deal and post-deal scenarios is fundamental. Market structure, on the other hand, describes how markets work and how economic agents interact with each other. This description is presented in mathematical terms. Network architecture and market structure are both formally described as follows.

2.2.1. Network architecture

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 ($g_{ij} = 1 \ \forall \ i,j \in$ N) and corresponds to global free trade, and Network g^e is the empty network ($g_{ij} = 0 \ \forall \ i,j \in$

N) and corresponds to a network in which all countries do not have an agreement (i.e. there are no FTAs in existence between countries). Let *G* denote the set of all possible networks of international agreements between countries. Let $Ni(g) = \{j \ \forall \ N: g_{ij} = 1\}$ be the set of countries with whom country *i* has an international trade agreement in network *g*. We assume that $i \in N_i(g)$.

2.2.2. Market structure

The IAFTN model assumes 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:

$$Q_i^f(g) = n_i^i q_i^i(g) + n_i^i q_j^i(g) + n_i^i q_k^i(g) + n_i^i q_l^i(g) + n_i^i q_m^i(g) \tag{2}$$

where *i*, *j*, *k*, *l* and m are the five 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):

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

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):

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

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

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:

$$Q_i^i(g) = n_i^i q_i^i(g) \tag{6}$$

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

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 under the Cournot oligopoly model in the markets where they sell their output. A particular intermediary 1 in country *j* is assumed to maximise the following total profit function:

$$\pi_1(g) = \sum_{i \in \Omega_j(g)} \pi_i^{j(1)}(g) + \sum_{k \notin \Omega_i(g)} \pi_k^{j(1)}(g) \tag{8}$$

Where $\Omega_j(g)$ is the set of countries having an agreement with country *j.* Note that $j \in \Omega_j(g)$. The optimisation problem would depend on whether the target market belongs to a country having or not having an agreement. If countries *i* and *j* have an agreement, then:

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

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:

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

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

$$\frac{\partial \pi_i^{j(1)}(g)}{\partial q_i^j(g)} = P_i^{-i}(g) - P_j^f(g) - \left(\beta_i^{-i} + \theta\right) q_i^j(g) \tag{11}$$

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

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

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

$$Q_i^j(g) = n_j^j q_i^j(g) = n_j \left[\frac{\alpha_i^{-i} - \gamma_j - \beta_i^{-i}\left(n_k^k q_i^k(g) + n_l^l q_i^l(g)\right) - k n_i^i q_i^i(g) - \theta Q_{j-i}^f(g)}{\left(\beta_i^{-i} + \theta\right)\left(n_j^j + 1\right)}\right] \tag{13}$$

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:

$$\pi_i^{k(1)}(g) = q_i^k(g)\left[P_i^{-i}(g) - P_k^f(g) - T_k^i(g)\right] \tag{14}$$

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:

$$Q_i^k(g) = n_k^k q_i^k(g) = n_k^k \left[\frac{\alpha_i^{-i} - \gamma_k - T_k^i(g) - \beta_i^{-i}\left(n_j^j q_i^j(g) + n_l^l q_i^l(g)\right) - k n_i^i q_i^i(g) - \theta Q_{k-i}^f(g)}{\left(\beta_i^{-i} + \theta\right)\left(n_k^k + 1\right)}\right] \tag{15}$$

Finally, these outputs are used to get expressions for the components of the welfare function:

$$W_i(g) = CS_i(g) + \pi_i(g) + PS_i(g) + TR_i(g) \tag{16}$$

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*; and $TR_i(g)$ is tariff revenue. Expressions for $CS_i(g)$, $\pi_i(g)$, $PS_i(g)$ and $TR_i(g)$ are obtained using the optimal output in Expressions 13 and 15:

$$CS_i(g) = \frac{\beta_i^i Q_i^{i2}(g) + \beta_i^{-i}\left(Q_i^j(g) + Q_i^k(g) + Q_i^l(g)\right)^2 + 2kQ_i^i(g)\left(Q_i^j(g) + Q_i^k(g) + Q_i^l(g)\right)}{2} \tag{17}$$

$$\pi_i(g) = \sum_{j \in N_i(g)} n_i^i \pi_i^i(g) + \sum_{k\text{Ï}N_i(g)} n_k^k \pi_i^k(g) = \sum_{j \in N_i(g)} \frac{\left(\beta_i^i + \theta\right)}{n_i^i} Q_i^{i2}(g) + \sum_{k \notin N_i(g)} \frac{\left(\beta_i^{-i} + \theta\right)}{n_k^k} Q_i^{k2}(g) \tag{18}$$

$$PS_i(g) = \frac{\theta}{2} Q_i^{f2}(g) = \frac{\theta}{2}\left(Q_i^i(g) + Q_j^i(g) + Q_k^i(g) + Q_l^i(g)\right)^2 \tag{19}$$

$$TR_i(g) = \textstyle\sum_{k\text{Ï}N_i(g)} T_k^i(g) Q_i^k(g) \tag{20}$$

Numerical estimations are obtained when adopting specific values of the parameters used in the model. As explained in Section 5, some of them are estimated, others are obtained from previous investigations, and others by means such as consultation with experts.

4. Extensions to the IAFTN

The IAFTN was first used to make predictions for the UK/Australia deal. This version of the model considered only four nodes and was solved by estimating the optimal tariff that maximise social welfare. After reflecting on the simulation process, it was found that beneficial extensions could be made to facilitate the calibration task, and to extend the number of nodes.

The first extension is the use of actual data on tariffs rather than estimated tariffs from the optimisation process. This strategy permitted working with less parameters because welfare maximisation requires knowing the weights that the government puts on the components of the welfare function. These weights reflect policy biases and are difficult to obtain or justify. By using actual data on tariffs, the calibration task became simpler and more straightforward.

The second extension is the introduction of an additional node into the network. This made the network approach more robust and representative. In relation to this extension, it is important to highlight that adding additional nodes was not possible when the model was solved by estimating optimal tariffs that maximise national welfare, given the mathematical complexity involved. In contrast, using current data of tariffs made it possible to extend the size of the network without increasing complexity.

5. Calibration process

The IAFTN has a number of parameters that need to be determined before simulations are carried out. These parameters are not normally available in the public domain and they need to be estimated or represented by means of proxies. In addition, the data that is needed to run simulations is not fully available in the public domain. This section explains how the database was obtained and how values for key parameters were estimated.

5.1. Database

The data sources used are provided below:

- IHS Maritime & Trade – Global Trade Atlas®
- Defra
- USDA
- FAO
- AHDB
- Beef & Lamb New Zealand
- Global Data
- WTO tariff database
- UK Government
- EU TARIC database
- US International Trade Commission
- New Zealand Foreign Affairs and Trade
- Cheese Market News (New Zealand)

The data used was averaged over three years (2018–2020).

Weighted tariffs were calculated for beef, lamb/sheep meat, cheese, and butter. Due to complexities associated with pork, a particular pork product (frozen pork shoulder) was selected. Information regarding existing Tariff Rate Quotas for imports was also taken into account.

The effects of non-tariff measures (NTMs) were also considered. Non-tariff measures (NTMs) are defined as policy measures, other than ordinary customs tariffs, that can potentially have an economic effect on international trade in goods, changing quantities traded or prices or both.

Unlike tariffs, which are clear, transparent and relatively easy to calculate per load, NTMs are complicated, opaque and very hard to calculate.

NTMs – also referred to as 'trade friction' or the 'cost of doing business' for exporters – consist of a variety of costs incurred when transporting goods from one country to another. Anything that slows the process down or adds costs to an exporter, compared to trading within a single market, may be referred to as trade friction.

Not all NTMs are bad. The main non-tariff measures relate to proving compliance with Sanitary and Phytosanitary Standards (SPS) and Technical Barriers to Trade (TBT).

SPSs exist to protect food safety and animal and plant life, whereas TBTs relate to technical regulations, standards, and conformity assessment for goods. Under WTO guidelines, neither are supposed to create barriers to trade (Non-Tariff Barriers or NTBs), but in practice this may often be the case.

Table 1 – Types of NTMs

Trade		**NTM description**
Imports	Technical Measures	Sanitary and Phytosanitary Measures (SPS) Technical Barriers to Trade (TBT) Pre-shipment inspection and other formalities
	Non-technical Measures	Contingent trade-protective measures Non-automatic licensing, quotas, prohibitions and quantity control measures other than SPS and TBT reasons Price control measures including additional taxes and charges Finance measures Measures affecting competition Trade-related investment measures Distribution restrictions Restrictions on post-sale services Subsidies (excluding export subsidies) Government procurement restrictions Intellectual property Rules of origin
Exports		Export-related measures

Source: UNCTAD 2012

Trading businesses sometimes have to overcome considerable NTMs, amounting to large costs and delays. Because time costs money the delivery of goods has become tailored to specific orders, leading to 'just-in-time' food supply. Frictions to trade that result in delays are, therefore, particularly critical to rapidly perishable food. Delays in shipments caused by checks, administrations, inspections and border controls could cause problems with this trade, and potentially lead to wastage of fresh meat in transit (Haverty, 2017). The Organisation for Economic Co-operation and Development

(OECD) suggests that non-tariff frictions, particularly at the border, can be larger than the costs of the tariffs themselves for many commodities and trade routes. It states that customs compliance costs add 2% to 24% to the value of traded goods with smaller businesses being disproportionately affected (Moïse and Le Bris, 2013). It also notes that the additional time taken to cross borders often adds up to even more, especially if it makes the goods valueless.

The impact of NTMs in the agri-food sector has been widely recognised in the literature and the different approaches to quantifying their impact identified. The issue is closely examined in the AHDB report 'Red Meat Route to Market' available here.

NTMs will vary according to the level of trust between trading partners. Although SPS and TBT standards exist in all trade, trusted trading partners such as New Zealand and the UK may only physically examine one in 100 loads. Less familiar trading partners may check every load arriving on their shores, which will increase costs and delays.

As a general rule, Free Trade Agreements (FTAs) will lower NTMs between parties.

Considering previous work published in the Red Meat to Market Report (carried out by The Andersons Centre for AHDB, QMS and HCC), a value of 1.3% for NTM was adopted for lamb. While this value is low, it was considered important to capture some effects of the UK-New Zealand trade deal because it is unlikely that tariff reduction would make an impact, as the current quota has not been filled.

5.2. Parameters of the model

The IAFTN contains several parameters that need to be estimated. They can be classified as parameters of demand, parameters of supply and number of intermediaries in a country.

The parameters of demand correspond to the slope of the inverse demand function and the coefficient of product differentiation. These parameters were obtained by means of current data on output, prices, elasticities of demand and cross-elasticities between domestic and imported goods. Elasticities of demand were not available for all countries in the network, therefore figures reported by academic articles were considered as a reference for these elasticities. Cross-elasticities were not available and assumptions were made following consultation with AHDB experts. Selected values for the elasticities were used in the model; final values were selected after sensitivity analysis and discussion with AHDB experts had been concluded.

On the other hand, the parameters of supply correspond to the slope of the inverse supply function (a key parameter to model imperfect competition) and the intercept. Estimations for these parameters were obtained from current data on output, farmgate prices and elasticity of supply. As in the previous case, sensitivity analysis and consultation with AHDB experts were considered because the elasticity of supply is not available in the public domain.

6. Summary

The simulations carried out for the UK-New Zealand deal were developed by a partial equilibrium network model referred to as the International Agri-Food Trade Network (IAFTN) model. This model considers several features that characterise the real world, such as, imperfect competition (i.e. oligopsony and oligopoly) associated with the presence of powerful intermediaries, and product differentiation. This model represents the world as a network in which nodes correspond to countries or set of countries and links as FTAs. Predictions are carried out by comparing different network structures that result from shocks such as the signature of a new agreement. Secondary data is employed to run the model after a calibration process is finished. This includes data on output, prices (retail and farmgate), tariffs and non-tariff measures. The model is calibrated using a range of sources including academic articles, reports and the experts' opinions. Key information that is needed for this calibration are elasticities of demand, supply and cross-elasticities for domestic and imported goods.

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