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The Tariff Equivalent and Forgone Trade Effects of Prohibitive Technical Barriers to Trade

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Abstract

We derive a method to econometrically estimate the tariff equivalent and foregone trade effects of a prohibitive technical barrier to trade (TBT) based on Wales and Woodland's Kuhn-Tucker approach to corner solutions in consumer choice. The method overcomes the lack of observed data on bilateral trade flows and accounts for differentiated goods by place of origin. We apply the derived random utility model to international trade in apples to identify the tariff equivalent of prohibitive phytosanitary barriers imposed by Australia on potential imports of New Zealand apples. We estimate the forgone apple trade between the two countries, the implied trade injury imposed by Australia on New Zealand, and the welfare loss to Australia. The removal of the Australian policy would induce net welfare gains around US$50 million annually for Australia.

Keywords: Corner solution, Kuhn-Tucker model, New Zealand apples, nontariff barrier, NTB, prohibitive, random utility, TBT, technical barrier to trade, SPS, phytosanitary.

JEL Code: F13, Q17

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Introduction

Many countries implement drastic measures to restrict trade in a product associated with a perceived or actual risk of transferring a pest or disease into their geography. These occurrences of nontariff trade barriers for human or plant health have increased as tariffs have been falling worldwide (Beghin (2008)). Trade agreements recognize countries' right to set their own standards and regulations on trade in order to protect human, animal, or plant health or life. For example, two World Trade Organization (WTO) agreements, the Sanitary and Phytosanitary (SPS) Measures Agreement and the Technical Barriers to Trade (TBT) Agreement, allow countries to set their own standards to protect plant and human health. These agreements, however, require that the standards adopted not to be discriminatory or protectionist. In practice, some countries impose stricter-than-necessary conditions on imported goods to isolate domestic producers from international competition (James and Anderson, 1998). In addition to the existing tariff barriers, the stricter regulations may lead to questionable impediments to imports that compete with domestic products. When the possibility of a disease or pest transmission is very low or threat to food safety is negligible, these trade impediments cause welfare losses for importing countries and mercantilist losses ("injury" in WTO language) for exporting countries due to reduced exports. These strict production, storage, and inspection requirements induce a higher unit cost, and higher price of the imported goods, and in some extreme cases, trade vanishes with prohibitive requirements. When trade flows do not exist, estimation of the tariff equivalent of SPS regulation or TBT is a challenging task because no reference imports exist and because part of the tariff equivalent will be redundant[1] when the policy is strictly prohibitive. Quantifying the impact of the removal of the SPS regulation or TBT is also difficult for the same reasons.

In this paper, we derive a new way to estimate the tariff equivalent and trade effects of a prohibitive TBT or SPS measure based on Wales and Woodland's Kuhn-Tucker approach to corner solutions in consumer choice. This approach has been successfully applied to a random utility model of recreation demand in environmental economics (e.g., Phaneuf, Kling, and Herriges, 2000). The latter authors apply the Kuhn-Tucker approach to recreation demand for fishing sites. The random utility model accounts for the fact that consumers do not fish at all the recreation sites. The demands for some sites for some particular consumers are systematically zero because of the higher transportation cost or personal preferences. Our approach to zero trade is similar in spirit. Because of trade costs (TBT, distance, and tariffs) and/or preferences, some consumers in a given country never consume a subset of the importable goods. Our contribution is to coherently integrate trade cost in the pricing of goods across borders into the random utility framework of Wales and Woodland, which predicts when corner solutions are likely to emerge in an internally consistent utility maximization framework. The framework incorporates the restrictions of utility theory and the behavioral implications of corner solutions. It allows recovery of the implicit prices inclusive of trade costs at which trade has vanished. The forgone trade and associated welfare losses can also be derived.

A large empirical literature exists on how to measure technical barriers and their effects when imports are positive. The price-wedge approach is often used to estimate the tariff

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[1] Just binding corners in consumption imply a marginal rate of substitution just equal to relative prices inclusive of the trade cost and the TBT, hence an exactly prohibitive tariff. Strictly binding corners (marginal rate of substitution not equal to relative prices), imply a strictly prohibitive tariff equivalent, hence a redundant component in the tariff equivalent.

equivalent and trade impact of a technical barrier. Most applications of the tariff equivalent assume perfect substitution of domestic and imported goods and measure the tariff equivalent as the difference between the domestic protected price and the world price (Calvin and Krissoff, 1998; Deardorff and Stern, 1998; James and Anderson, 1998). Yue, Beghin, and Jensen (2006) have extended that approach of estimating the tariff equivalent of TBTs by accounting for imperfect substitution of domestic and imported goods, consumers' home good preference, and trade costs. Their method still relies on positive trade flows to identify the tariff equivalent of the TBT or SPS measure. Despite these improvements and its usefulness, the price wedge approach has some caveats. It can overstate the cost of incriminated technical barriers by potentially omitting some other sources of trade costs or other variables that may contribute to the price wedge.

Kee, Nicita and Olarreaga (2006) econometrically estimate the impacts of numerous non tariff barriers (NTB) on trade flows for a large number of commodities and countries but without accounting for prices. Then they recover the tariff equivalent of these NTBs using corresponding own-price elasticities of import demand generated separately. Disdier, Fontagné and Mimouni (2008) use the latter estimates in an investigation of the effects of TBTs in global agricultural trade. Andriamananjara et al. (2004) also provide a tariff equivalent of NTBs by regressing observed retail price gaps between major cities on nontariff barriers indicators, using a simple "average" quality approach to product differentiation. Again, trade flows have to be observed to compute these prices, which are biased downward because they exclude the price of goods facing prohibitive barriers.

Some literature shows how to predict trade volume using the Tobit model when many trade observations contain zero values. For example, Eaton and Tamura (1994) recommend adopting the threshold Tobit model in which trade volume appears to be positive only when desired trade exceeds some minimum threshold. However, most investigations of trade costs attempting to explain trade flows use the gravity equation approach with log(1+trade) as the dependent variable to overcome the problem of zero trade flow instead of using the Tobit model (e.g., Disdier, Fontagné, and Mimouni, 2008; see also Feenstra, 2004, chapter 5). More recently, Ranjan and Tobias (2007) propose a Bayesian procedure for estimating a generalized threshold Tobit model to avoid adding unity arbitrarily to the dependent variable to circumvent taking the log of zero. The latter authors do not consider price or TBTs as determinants of trade flows.[2] The mentioned literature used different ways to deal with zero trade volume, yet none of them is related to the estimation of the tariff equivalent and trade effect of a TBT when trade volume is systematically zero for all observations of bilateral trade between two countries. This problem is likely to arise in the case of bilateral trade data for disaggregated sectors or a single commodity. The problem is policy relevant as disaggregated products are at the heart of many trade disputes (e.g., apple, cotton, computer chips, specific meat products).

Additionally to addressing the prohibitive TBT, we account for consumers' heterogeneous preferences for substitute goods by place of origin. We do so to avoid problems arising from assuming homogeneous goods in the computation of the tariff equivalent of a policy and its effects (Salerian, Davis, and Jomini, 1999; Yue, Beghin, and Jensen, 2006). Imperfect substitution tends to increase the size of the tariff equivalent but decreases the import expansion following the policy elimination. Extensive applied literature since Armington's seminal paper shows that consumers have different preferences for close substitute disaggregated food goods from different countries.

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[2] See also Martin and Pham (2008) for an extensive coverage of treatments of zeros in gravity equations.

Using recent data and the proposed new approach, we provide a policy-relevant investigation of Australian phytosanitary regulations imposed on imports of New Zealand apples because of the alleged risk of introducing fire blight in Australian orchards. We compute the tariff equivalent of this Australian SPS regulation impeding bilateral apple trade between Australia and New Zealand and quantify the impact of removing this regulation policy on apple trade flows and welfare. The removal of the barriers would induce net welfare gains around US$50 millions annually for Australia; forgone apple trade amounts to about 50 million metric tons valued at around US$35 to US$40 millions.

This application has much policy relevance as the New Zealand-Australia apple dispute has lasted for more than 80 years without being effectively resolved. As further explained later, prohibitive SPS requirements make it impossible to export apples from New Zealand to Australia. A related apple trade dispute between Japan and the United States was resolved in the summer of 2005 through a WTO dispute settlement body. The WTO rulings required Japan to remove its fire blight regulations because they were not science based and constituted protectionism (WTO, 2005). These rulings have great potential to boost the case of New Zealand against the Australian fire blight regulations, which in essence are also protectionist. Mature fruit that are shown to be free of symptoms are not effective carriers of fire blight and do not require the extensive procedure dictated by the Australian SPS regulations (WTO, 2005).

The next section introduces the Kuhn-Tucker model and the derivation of the system of equations to be empirical estimated to recover preference parameters and the tariff equivalent of technical measures on prices. Then data and estimation results are presented, followed by the welfare computations. Policy implications are discussed in the conclusion section.

Conceptual model for the econometric estimation of a prohibitive technical barrier

Suppose the typical consumer in a given country maximizes utility of consuming market goods (**x**, *AOG*) subject to a budget constraint, or

$$\underset{\mathbf{x},AOG}{Max}\, U(\mathbf{x}, AOG, \mathbf{y}; \boldsymbol{\delta}, \boldsymbol{\eta}, \boldsymbol{\varepsilon}, \boldsymbol{\Omega}) = \sum_{j=1}^{M} \psi_j(\mathbf{y}, \boldsymbol{\eta}_j, \delta_j, \varepsilon_j) \ln(x_j + \Omega_j) + v(AOG)$$

$$s.t.\ \mathbf{p}'\mathbf{x} + AOG \le I \qquad (1)$$

$$AOG \ge 0$$
$$\mathbf{x} \ge 0,$$

where $\mathbf{x} = (x_1, \cdots, x_M)'$ is the vector of consumer goods of interest in the analysis and *AOG* is an aggregate all other goods assumed to be the numéraire; $\mathbf{y}$ is a vector of socio-demographic information of consumers in the importing country impacting preferences for **x** through parameters $\boldsymbol{\eta}$; $\boldsymbol{\delta}$ is vector of preferences for attributes of **x** not based on socio-demographics (country of origin, for example). Vector $\boldsymbol{\varepsilon} = (\varepsilon_1, \cdots, \varepsilon_M)'$ is a vector of random components capturing preference variation known to the consumer but not to the researcher; $\boldsymbol{\Omega}$ is the vector of taste parameters expressing minimum consumption thresholds; weights $\psi_j(\mathbf{y}, \boldsymbol{\eta}_j, \delta_j, \varepsilon_j) = \exp(\boldsymbol{\eta}_j'\mathbf{y} + \delta_j + \varepsilon_j)$ represent consumers' preference in the importing country for heterogeneous product x_j; function *v* expresses how AOG relates to utility. Finally, $\mathbf{p} = (p_1, \cdots, p_M)'$ is the vector of associated consumer prices including trade costs (transportation, and trade barriers); *I* is the income of the representative consumer.

Consumer prices in the given country are further decomposed into an export unit cost component and trade costs arising from distance (transportation cost), tariffs, and technical barriers to trade. For good *j*, this consumer price is $p_j = (wp_j + \gamma d_j)(1 + t_j + TBT_j)$, where $\mathbf{wp} = (wp_1, \cdots, wp_M)'$ is the vector of world prices/export unit costs for goods **x;** γd_j represents the transportation cost to bring good j (i.e. produced in country j) to the importing country. Vector $\mathbf{d}=(d_1,\cdots,d_M)'$ represents distances between the product sources and the importing country under consideration, and γ is the unit rate of transportation cost and associated fees. For simplicity, we assume the unit rate to be the same per unit of distance. The latter is acceptable as we have in mind applications to single commodities, which are similar in terms of transportation characteristics. Transportation cost enters price as per unit cost component given the recent evidence in favor of the latter formulation (Hummels and Skiba, 2004). The latter authors found that a specific (dollars per unit) specification of shipping cost was econometrically superior to an ad-valorem (% of unit price) one in applied trade analysis. Shipping cost shifts the supply faced by consumers in a parallel manner rather than proportionally. Vector $\mathbf{t}=(t_1,\cdots,t_M)'$ is the vector of ad valorem tariff imposed by the importing country on foreign goods **x**; vector $\mathbf{TBT}=(TBT_1,\cdots,TBT_M)'$ represents the ad-valorem tariff equivalent of TBTs and SPS measures increasing the cost of products in that importing country. TBT_j is set equal to zero for domestic and imported products in countries without technical barriers to trade.[3]

The corresponding first-order necessary and sufficient Kuhn-Tucker conditions are

$$U_{x_j}(\mathbf{x},AOG,\mathbf{y};\boldsymbol{\delta},\boldsymbol{\eta},\boldsymbol{\Omega},\boldsymbol{\varepsilon})=\frac{\partial U(.)}{\partial x_j}\leq\lambda(wp_j+\gamma d_j)(1+t_j+TBT_j),\ x_j\geq 0, \tag{2}$$

$$x_j[U_{x_j}(.)-\lambda(wp_j+\gamma d_j)(1+t_j+TBT_j)]=0,\ \ j=1,\cdots,M, \tag{3}$$

$$U_{AOG}(AOG)=\frac{\partial U(.)}{\partial AOG}\leq\lambda\,,\ \ AOG\geq 0\,, \tag{4}$$

[3] The measures imposed by Australia are strictly speaking SPS measures. While broadly speaking, they could be considered TBTs as their economic effects are similar to TBTs. In the WTO, the agreements governing SPS and TBT measures and the burden of proof in a dispute over these agreements are different (Wilson) . Hence, we refer to SPS measures when we analyze the Australian case in later sections.

$$AOG[U_{AOG}(.)-\lambda]=0\,, \tag{5}$$

with $U_{x_j}(.)=\dfrac{\psi_j(\mathbf{y},\boldsymbol{\eta}_j,\delta_j,\varepsilon_j)}{x_j+\Omega_j}=\dfrac{\exp(\boldsymbol{\eta}_j'\mathbf{y}+\delta_j+\varepsilon_j)}{x_j+\Omega_j}$, and with λ being the marginal utility of income. For simplicity, we assume the consumption of the numéraire good is positive, or $AOG>0$. We have $\lambda=U_{AOG}(.)=v'(AOG)$. Therefore, (2) and (3) translate into

$$U_{x_j}(.)=\frac{\exp(\boldsymbol{\eta}_j'\mathbf{y}+\delta_j+\varepsilon_j)}{x_j+\Omega_j}=v'(AOG)(wp_j+\gamma d_j)(1+t_j+TBT_j)\ \text{ when }\ x_j>0\,, \tag{6}$$

and

$$U_{x_j}(.)=\frac{\exp(\boldsymbol{\eta}_j'\mathbf{y}+\delta_j+\varepsilon_j)}{x_j+\Omega_j}\le v'(AOG)(wp_j+\gamma d_j)(1+t_j+TBT_j)\ \text{ when }\ x_j=0 \tag{7}$$

Using a simple rearrangement of terms in (6) and (7), we define

$$\begin{aligned}&g_j(\mathbf{x},\mathbf{y},\mathbf{wp},\mathbf{d},\mathbf{t};\mathbf{TBT},\boldsymbol{\delta},\boldsymbol{\Omega},\gamma,\boldsymbol{\eta}_j)=\\&\ln\left[v'(AOG)(wp_j+\gamma d_j)(1+t_j+TBT_j)(x_j+\Omega_j)\right]-\delta_j-\boldsymbol{\eta}_j'\mathbf{y}\end{aligned} \tag{8}$$

Then, conditions (6) and (7) are expressed as

$$\varepsilon_j=g_j(\mathbf{x},\mathbf{y},\mathbf{wp},\mathbf{d},\mathbf{t};\mathbf{TBT},\boldsymbol{\delta},\boldsymbol{\Omega},\gamma,\boldsymbol{\eta}_j)\ \text{ when }\ x_j>0\,, \tag{9}$$

and

$$\varepsilon_j\le g_j(\mathbf{x},\mathbf{y},\mathbf{wp},\mathbf{d},\mathbf{t};\mathbf{TBT},\boldsymbol{\delta},\boldsymbol{\Omega},\gamma,\boldsymbol{\eta}_j)\ \text{ when }\ x_j=0\,. \tag{10}$$

The specification of the joint density function $f_\varepsilon(\boldsymbol{\varepsilon})$ together with the above expressions of ε_j's provide necessary information to set up the likelihood function for estimation. Suppose a given consumer's first *K* commodities' consumption is zero, and remaining *K*+1 to *M* commodities' consumption is positive (that is, $x_j=0,\ j=1,\ldots,K$, and $x_j>0,\ j=K+1,\ldots,M$). Then, this consumer's contribution to the likelihood function is given by the following probability *f*:

$$f = \int_{-\infty}^{g_1} \cdots \int_{-\infty}^{g_K} f_\varepsilon(\varepsilon_1, \cdots, \varepsilon_K, g_{K+1}, \cdots, g_M) \times |\boldsymbol{J}| \, d\varepsilon_1 \cdots d\varepsilon_K \,, \tag{11}$$

where $\boldsymbol{J}$ denotes the determinant of the Jacobian matrix for the transformation from $\boldsymbol{\varepsilon}$ to $(\varepsilon_1, \cdots, \varepsilon_K, x_{K+1}, \cdots, x_M)$.

We assume that the ε_j's are identical and independent, and follow the standard normal distribution. Assuming N available observations, the log-likelihood function to be used to estimate the tariff equivalent **TBT** and parameters $\boldsymbol{\delta}$, $\boldsymbol{\Omega}$, γ, and $\boldsymbol{\eta}$ is

$$l = \sum_{i=1}^{N} \left(\sum_{j=1}^{K_i} \ln(\Phi_i(g_j)) + \sum_{j=K_i+1}^{M} \ln(\phi_i(g_j)) + \ln|\boldsymbol{J}_i| \right), \tag{12}$$

where i indicates observation i and i=1,…,N; and j is commodity j and j=1,…, M; Φ is the cumulative density function of standard normal distribution for the goods that are not consumed, and ϕ is the density function of standard normal distribution for the goods that are consumed.

Application to Australian SPS regulations on apple trade

The competitiveness of Australian and New Zealand apple industries

Apple industry experts rank New Zealand apples first among apples exporters, ahead of Chile and European exporters and Australia, based on various criteria (productivity, quality, price, input and infrastructure) (World Apple Report, 2000; Dixon and Hewett, 2000; Ministry of Agriculture and Forestry, New Zealand). New Zealand exports about 55% of its total crop, which is higher than any other significant export competitor (McKenna and Murray, 2002). This large share of production going to world markets suggest that these apples are competitive in export markets and well liked by world consumers.

Australian policies and the apple dispute with New Zealand

Despite the high quality and relatively low cost of New Zealand apples, Australia has prohibited importation of New Zealand apples since 1921 to protect Australia from fire blight, a disease caused by a bacterium called *erwinia amylovora*, which affect apple and pear trees. At the time fire blight was absent on Australian soil (Binder, 2002). In 1919, fire blight was discovered in Auckland, New Zealand. Two years later, Australia banned imports of New Zealand apples. In 1983, Australia and New Zealand set up the Australia–New Zealand Closer Economic Relations Trade Agreement. Under this agreement, the elimination of all tariffs and quantitative restrictions was achieved in 1990, with apples as one of the most notable exceptions.

Between 1986 and 1995, New Zealand repeatedly applied to export apples to Australia but the applications were declined. In 1997, Australia released its Pest Risk Analysis regarding apple imports from New Zealand. In the same year, New Zealand observed fire blight in the Melbourne Royal Botanic Gardens. In 1998, the Australian Quarantine and Inspection Service (AQIS) released a draft risk assessment refusing imports of New Zealand apples. One year later, in 1999, New Zealand requested a review of available risk management options for apple exports from that country. In 2000, the Australian Department of Agriculture, Fisheries and Forestry proposed allowing imports of New Zealand apples but imposed the world's strictest biosecurity conditions (See Binder (2002) for a detailed list of these conditions). In 2001, AQIS recommended lifting the 80-year ban, but this recommendation was rejected by the Australian Senate Rural Affairs Committee.

In 2004, the Australian Department of Agriculture, Fisheries and Forestry released an import risk analysis and recommended admitting apple imports from New Zealand subject to stringent controls. In 2006, the final risk assessment by Australia allowed imports of New Zealand apples into every state except Western Australia. However, the New Zealand government and apple growers charged that the technical conditions set by Australia were not materially changed and were so strict that few of the apple growers if any would be able to afford exporting to Australia. The conditions include orchard inspections of fire blight and European canker symptoms in New Zealand, the utilization of disinfection treatments in packing houses, and auditing with the involvement of the AQIS, among other things. Associated SPS measures also contested by New Zealand address apple leafcurling midge (WTO 2007). New Zealand ministers and growers thought this move ignored scientifically based argument and was effectively a trade barrier. After consultations with Australia failed in 2007, New Zealand requested the establishment of a WTO dispute panel to investigate the Australian SPS policies (WTO 2007). In early 2008, The WTO established a panel to investigate the consistency of the Australian apple policy with the WTO SPS agreement (WTO 2008).

Data, econometric estimation, and results

The derived framework is applied to the Australian SPS measures precluding imports of New Zealand apples. Three types of apples are considered (Australia, New Zealand, aggregate others); they are differentiated by subscript j (*j=AU, NZ* and *Other*). Vector $\mathbf{x}_c = (x_{AUc}, x_{NZc}, x_{Otherc})$ represents per capita consumption of the three kinds of apples in any country *c* included in the data set. For instance, x_{AUc} is a vector of per capita consumption of Australian apples in any country c (Bangladesh, Barbados, etc…) which consumes Australian apples; x_{AUAU} is simply the per capita consumption of the domestic apples in Australia, and x_{NZAU} is the per capita consumption of New Zealand apple in Australia which is zero. Similarly, x_{NZNZ} is the per capita consumption of domestic apples in New Zealand. This grouping allows us to identify the relative preferences between Australian and New Zealand apples and the tariff equivalent of the policies affecting the potential flow of New Zealand apples to Australia.

To estimate the tariff equivalent of the Australian barriers brought by the strict conditions imposed by Australia on imports of New Zealand apples, we incorporate a panel of 38 countries over time, including the United States, European countries, Canada, Singapore, Bangladesh, China, India, Malaysia, Indonesia, Philippines, Sri Lanka, Thailand, Australia, New Zealand, and others as observations of our representative consumer. The countries and data years are listed in appendix table 1 (available on Agecon Search). We included all countries having multi-year data on apple trade either with New Zealand or Australia as reported by UN Comtrade and having fresh apple consumption and production data reported by FAO.

We simply capture the individual socio-demographic effects in any country *c* by including its development level approximated by per-capita GDP (scalar y_c = per capita GDP in country *c*) in the utility function to see how the marginal utility of each apple type varies as consumer income grows. The influence of *y* on apple type *j* is captured by parameter η_j (now a scalar) in equation (8).

Aggregate fresh apple consumption data come from FAO. Population, and bilateral export quantities and prices data come from the United Nations' Comtrade database. Per capita consumption of the three apple types in a country is defined as follows: x_{AUc} is the bilateral flow of Australian apples to that country *c* (for $c \neq$ Australia) normalized by its population; In Australia, x_{AUAU} is the total consumption of domestic apples normalized by Australian population. Variable x_{NZc} is a flow of New Zealand apples to country *c* normalized by *c*'s population ($c \neq$ New Zealand). In New Zealand, x_{NZNZ} is the total consumption of domestic apples normalized by New Zealand's population. Last, x_{Otherc} is aggregate consumption of apple in country *c* minus the sum of Australian and New Zealand apples flows to country *c*, also normalized by *c*'s population. In Australia and New Zealand, domestic consumption of domestic apples is defined as the aggregate apple consumption of the respective country minus total imported apples, then normalized by respective population to be expressed in a per capita basis. Per capita consumption of other apples in these two countries ($x_{OtherAU}$ and $x_{OtherNZ}$) is defined as their respective total imports normalized by their population since neither Australia nor New Zealand do trade apples with each other.

The bilateral export prices for Australian apples (wp_{AU}) and New Zealand apples (wp_{NZ}) are free-on-board (FOB) prices, which exclude international transportation fee and insurance). The latter costs are explicitly accounted for through trade costs associated with distance. The corresponding unit fee (dollar per kilometer per kilogram) is econometrically estimated (γ). The distances (d) between exporting and importing countries are sea distance via the Suez canal in kilometers (Hengeveld, 1999). When bilateral trade is zero, we use the FOB prices averaged over all other destinations for the same year as a proxy for the unobserved export price associated with the zero flow.

Outside of Australia and New Zealand, the price for all other apples is a consumption-weighted average of other imported fresh apples and domestically produced apples. The unit price of other imported apples is the cost, insurance, and freight (CIF) prices provided by FAO. The importing prices for all other apples are derived by using the value of imports (valued at CIF prices) of all other apples divided by the total weight of imports of all other apples in the importing country. We use CIF prices instead of FOB prices plus transportation cost to overcome the multiple sourcing and distances associated with other imported apples, instead of guessing d_{other} to eventually estimate $wp_{Other} + \gamma d_{Other}$. In Australia and New Zealand, the consumption of domestic apples is valued at their FOB price, which is a good approximation of the wholesale price (domestic producer price plus costs from farm to harbor/wholesale place). The tariff rates are obtained from WTO online tariff rate schedules. In Australia, tariffs and the tariff equivalent of the SPS policies are applied to imported apples from NZ, whereas in other countries, only tariffs are applied to imports. We have 413 observations.

The optimization method used in maximum likelihood estimation is the conjugate gradients method of Fletcher and Reeves (1964). The program is run in *R* version 2.4.1. The estimation results are shown in table 1.

With the exception of parameters $\boldsymbol{\eta}$, all parameters estimated have expected signs and are individually statistically different from zero at a 1% critical level or less. The estimate of *TBT*, the ad valorem equivalent of the SPS barriers Australia imposes on New Zealand apples, is on average about 99% of the FOB price inclusive of transportation cost ($wp_{NZ} + \gamma d_{NZAU}$) with d_{NZAU} being the bilateral distance. Estimated preference parameter $\hat{\delta}_{NZ}$ is greater than $\hat{\delta}_{AU}$, which indicates that the representative consumer prefers New Zealand apples to Australian apples. This result is in line with the findings of Dixon and Hewett (2000), who show that New Zealand apples are regarded as having premium quality. This results is also consistent with New Zealand apples export volumes to the world being much larger than those of Australian apples over the years. $\hat{\delta}_{Other}$ is the largest of the three δ estimates. It is explained by the predominance of domestic apple consumption in “other” countries relative to the consumption of traded apples. “Other” countries make the bulk of the dataset.

The average unit fee for international transportation and insurance γ is estimated to be \$8.55*10^{-5}/(km*kg). This is comparable to estimates provided by Calvin, Krissoff, and Foster (2008) on fees to transport apples from the United States to Japan. Estimated parameters $\hat{\boldsymbol{\eta}}$ measure how consumers’ marginal preferences for apples vary by country as characterized by their development level. The positive $\hat{\boldsymbol{\eta}}$ values indicate that the marginal utility of apples is higher in more developed countries but the estimates are not significantly different from zero.

Estimates of **Ω** are positive and significant, and since they are different from 1, weak complementary is rejected --attributes of goods do matter even if they are not consumed. **Ω** can also be rationalized as threshold minimum consumption levels as in Eaton and Tamura (1994), and Ranjan and Tobias (2007). Finally, the point estimate of the marginal utility of *AOG*, *v'(AOG)*, is significant and positive.

We have estimated alternative specifications with various assumptions on *v*(*AOG*), and restrictions on **η**, **Ω**, and **δ,** and using another algorithm (Nelder and Mead, 1965). We have obtained very similar results. The *TBT* estimates in these alternative runs remain significant and in the tight range of 0.70 to 1. Some models restricting **η** to be equal across apple types yield positive and significant estimates of **η**, but the latter result is not robust. Results of these alternative runs are available from the authors upon request.

The dollar value equivalent to *TBT* (in specific tariff form) changes across years as apple prices change. Table 2 shows the specific tariff equivalent of *TBT* (dollar per kg) from 2003 to 2005. The average of this specific tariff equivalent across the three years is $0.97/kg.

Welfare analysis

If the Australian SPS barriers were removed, Australian apple producers would face Marshallian surplus losses with the introduction of New Zealand apples. We use a small displacement model to endogenize and determine the price of domestic (Australian) apples and eventually infer the impact of removing the SPS barriers on imports and domestic (Australian) market equilibrium. We model the policy shock as setting *TBT* to be equal to zero. Let S_{AU} be the domestic supply of Australian apples, which is an increasing function of domestic apple price and exogenous parameter *v*:

$$S_{AU}(wp_{AU}, \upsilon) = \upsilon \; wp_{AU}^{\omega_S}. \tag{13}$$

Parameter ω_S represents the own-price elasticity of the domestic (Australian) apple supply. Decreases in parameter υ would reflect upward shifts in supply if phytosanitary contamination occurred with infested New Zealand imports, and induced an increase in the Australian cost of production. Equilibrium domestic price wp^e_{AU} and quantity are determined by the market equilibrium condition, or

$$S_{AU}(wp^e_{AU}, \upsilon) = X_{AUAU}(wp^e_{AU}, p_{NZAU}, p_{OtherAU}) + \sum_s X_{AU\ s}(wp^e_{AU} + \gamma d_{AUs} + t_{AUs}, p_{NZs}, p_{Others}), \quad (14)$$

with index and subscript s denoting the export destinations for Australian apples consumed abroad. The aggregate demand $X_{AUAU}(wp^e_{AU}, p_{NZAU}, p_{OtherAU})$ for Australian apples is the per capita demand for Australian apples by Australian consumers derived from the first-order conditions of the utility maximization and multiplied by population. A similar definition holds for $X_{AU\ s}$. Prices p_{ij} denotes the price of apple *i* in country *j*.

With the elimination of the SPS barriers (*TBT*=0), the internal price of New Zealand apples in Australia, p_{NZAU}, decreases whereas the internal price of Australian apples, wp_{AU}, will fall if there is no risk of contamination from the increased imports. The domestic demand for Australian apples declines with the change in p_{NZAU}. Then the domestic market adjusts at a lower price such that demand equals supply. Imports of New Zealand apples expand, as the direct effect of the decrease in the New Zealand price is larger than the feedback effect of the lower Australian domestic price, by stability. If fire blight contamination occurs, the price of Australian domestic apples may not decrease, as the domestic supply shifts upward to reflect the increased cost from contamination. The Australian domestic apple equilibrium quantity is further reduced by the disease contamination. Imports increase. For simplicity, we assume away feedback effects from apple suppliers into the income of the representative consumer.

The consumer welfare is measured using compensation variation (*CV*). Let $V(\mathbf{p}, I, \mathbf{y}; \boldsymbol{\delta}, \boldsymbol{\eta}, \boldsymbol{\Omega}, \boldsymbol{\varepsilon})$ denote the indirect utility function by maximizing the utility function defined in equation (1). The *CV* associated with a change in the price vectors from $\mathbf{p}^{\mathbf{0}}$ to $\mathbf{p}^1$ is defined by

$$V(\mathbf{p}^{\mathbf{0}}, I, \mathbf{y}; \boldsymbol{\delta}, \boldsymbol{\eta}, \boldsymbol{\Omega}, \boldsymbol{\varepsilon}) = V(\mathbf{p}^1, I - CV(\mathbf{p}^{\mathbf{0}}, \mathbf{p}^{\mathbf{1}}, I, \mathbf{y}; \boldsymbol{\delta}, \boldsymbol{\eta}, \boldsymbol{\Omega}, \boldsymbol{\varepsilon}), \mathbf{y}; \boldsymbol{\delta}, \boldsymbol{\eta}, \boldsymbol{\Omega}, \boldsymbol{\varepsilon}) \qquad (15)$$

The *CV* defined in (15) is a random variable since it is a function of $\boldsymbol{\varepsilon}$. We estimate the mean and standard deviation of *CV* to give policy implications based on a range of outcomes. In addition, there is no closed-form solution for *CV* or its mean due to the nonlinearity of the utility-maximization problem. Therefore, numerical bisection, which is one of the numerical techniques, is applied to solve this problem (Phaneuf, Kling and Herriges, 2000).

The random utility function is nonlinear with respect to the estimated parameters and random disturbance terms $\boldsymbol{\varepsilon}$ appear in the random utility function. Hence, the resulting demand functions, *CV* and producer surplus (*PS*) are nonlinear with respect to the estimated parameters and are functions of $\boldsymbol{\varepsilon}$. Because $E(h(\mathbf{x})) \neq h(E(\mathbf{x}))$ if $h(\mathbf{x})$ is a nonlinear function of $\mathbf{x}$ ($E(\mathbf{x})$ denotes the expectation of $\mathbf{x}$), we cannot substitute the mean values of the estimated parameters and $\boldsymbol{\varepsilon}$ into the demand, *CV* and *PS* functions to obtain the means of the associated measures. To avoid this problem we adopt the following numerical algorithm:

1) Draw the estimated parameters $\boldsymbol{\mu}$ (including $TBT, \boldsymbol{\delta}, \gamma,$ $\boldsymbol{\eta}$, and $\boldsymbol{\Omega}$) from the underlying asymptotic distribution, which are assumed to be asymptotically normal and repeat N_1 times;
2) For each $\boldsymbol{\mu}^{(i)}$ (i=1,…, N_1), draw the random disturbance terms $\boldsymbol{\varepsilon}$ from the assumed standard normal distribution and repeat N_2 times;
3) Substitute $\boldsymbol{\mu}^{(i)}$ and $\boldsymbol{\varepsilon}^{(j)}$ in equation (15) and use numerical bisection to solve for *CV*, which is denoted as $CV^{(i,j)}$; Substitute $\boldsymbol{\mu}^{(i)}$ and $\boldsymbol{\varepsilon}^{(j)}$ into the demand and *PS* functions and get the

$x_{NZ}^{(i,j)}$ and $PS^{(i,j)}$;

4) Average $CV^{(i,j)}$, $x_{NZ}^{(i,j)}$, and $PS^{(i,j)}$ over the N_2 draws of the disturbance terms and yield $\widehat{CV}^{(i)}$, $\hat{x}_{NZ}^{(i)}$, and $\widehat{PS}^{(i)}$,which gives a Monte Carlo integration valuation of $E_\varepsilon(CV^{(i)})$, $E_\varepsilon(x_{NZ}^{(i)})$ and $E_\varepsilon(PS^{(i)})$;

5) The distributions of $\widehat{CV}^{(i)}$'s, $\hat{x}_{NZ}^{(i)}$'s and $\widehat{PS}^{(i)}$'s provide the distribution of the mean of CV, x_{NZ}, and PS with respect to the uncertainty regarding the estimated parameters $\boldsymbol{\mu}$. Averaging $\widehat{CV}^{(i)}$, $\hat{x}_{NZ}^{(i)}$ and $\widehat{PS}^{(i)}$ over the N_1 draws of the parameters provides a consistent estimate of the mean of CV, x_{NZ}, and PS. We use the distribution of $\widehat{CV}^{(i)}$'s, $\hat{x}_{NZ}^{(i)}$'s, and $\widehat{PS}^{(i)}$'s to estimate the standard errors of the estimated mean of CV, x_{NZ} and PS.

Since Australian imports of New Zealand fresh apples have been zero over the years because of the import ban that preceded the prohibitive SPS measures, the increase in imports is simply the Australian consumers' optimal consumption quantity of New Zealand apples by maximizing their utility function. The above-mentioned algorithm is used to estimate the increase in New Zealand imports ($\Delta\hat{x}_{NZ}$), *CV* ($\widehat{CV}$) and change in *PS* ($\Delta\widehat{PS}$) induced by the removal of *TBT*. We set N_1 to be 100 and N_2 to be 1000. The average increasing amounts in New Zealand imports and the associated standard errors from 2003 to 2005 are shown in table 2. By eliminating *TBT*, Australian imports of New Zealand apples would increase substantially, between 47,400 MT and 54,407 MT, across the three years (3-year average import volume = 50,310 MT) . The dollar amount of this trade expansion provides a base to measure of the trade "injury" caused by Australia to New Zealand and is listed in the third column of table 2. It ranges from US$35.95 millions to US$39.25 millions over the three years.

Changes in welfare arising from the elimination of the TBT vary depending on the chosen assumption on the transmission of disease associated with the introduction of New Zealand apples. The elimination of the TBT leads to an increase in imports of New Zealand apples, which would increase the social welfare from consuming apples, other things being held constant. In the case of no disease transmission, the introduction of New Zealand apples lowers the price of Australian domestic apples through competition because of the lower price of New Zealand apples and the relatively small transportation fee due to the close distance between the two countries. The producers' welfare decreases. Nevertheless, because of the lower price of apples, consumers will be better off. The total social welfare change depends on the relative value of consumers' welfare and producers' welfare but with net expected gains as long as terms-of-trade effects are moderate.

However, in the case of disease transmission, the Australian domestic supply will further decrease because of the damage brought by fire blight contamination of Australian orchards. This will further deteriorate producers' welfare. Table 3 gives the welfare implications of eliminating the TBT between 2003 and 2005 in the no-disease transmission case. Following Arthur (2006), we assume a medium-term supply elasticity of apples to be 0.3.

CV and change of PS (ΔPS) are shown in the fifth and sixth columns of table 3, and the net welfare changes following the removal of *TBT* are shown in the last column. Not surprisingly, CV is larger than the loss of PS, and the net social welfare is positive across the years with gains to consumers being 2 to 3 times as large as producers' losses.

Following Yue, Beghin, and Jensen (2006) and Arthur (2006), we assume that production of apples would decrease by a fixed proportion of 20% in case of fire blight contamination of

Australian orchards. This estimate comes from the Queensland Government's Department of Primary Industries and Fisheries. Disease transmission shifts the Australian domestic supply of apples upward as the variable cost of production increases. The far right columns of Table 3 show the welfare implications with disease transmission.

From table 3, we see that when there is disease transmission, CV is lower compared with the case when there is no disease transmission and the loss of PS slightly increases although the increase in domestic price resulting from the supply shift almost compensates the loss induced by the disease. The net welfare through the years is still positive, which indicates that it is still optimal to eliminate the SPS policy even if there is a significant possibility of disease transmission. If we incorporate the welfare of both New Zealand and Australia, "global" social welfare would be enhanced further by the elimination of the policy.

One concern would be that these net gains results would be invalidated if the assumption of 20% reduction in domestic production underestimates the true impact of the disease as it spreads to Australia. We re-estimate the welfare consequences of eliminating the SPS policy assuming that domestic production reduction is 30% and then 40% respectively for the three years. We find that net welfare is still positive across the three years, and that these net welfare gains decrease nearly linearly in the production damage rate. A 50% proportional increase in the production reduction (from a 20% to a 30% reduction) decreases welfare gains by roughly $10.7 million (in 2003) as we find welfare gains of $28.12 million under a 30% reduction and of $17.49 million under a 40% reduction (in 2003). The detailed results are available from the authors. This further analysis confirms it is optimal for Australia to remove its policy even if the spread of fire blight brought severe damage to its domestic production.

To see how sensitive the welfare implication to the different assumption of supply elasticity of AU apples, we also calculate the welfare consequence of the SPS policy removal under the ω_S =0.2 and ω_S =0.4 respectively, assuming no disease transmission. Results are shown in table 4. Net welfare is still positive under the different assumed values of supply elasticities. Exact knowledge of the supply response of Australian apples is not pivotal to establish the positive net gains from eliminating the prohibitive barriers.

Conclusion

We tailor Wales and Woodland's approach to corner solutions in consumption decisions to the analysis of prohibitive nontariff trade barriers (TBTs, SPS measures). The random utility model is applied to actual and potential trade flows consumed by international consumers depending on trade costs associated with the importable goods and consumer preferences. Trade vanishes under prohibitive technical barriers and leads to corners. Technical barriers, transportation costs, and tariff are incorporated in the measurement of trade costs. Their influence is recovered in the estimation of Kuhn-Tucker conditions coming from maximizing utility.

Our paper bridges an important gap in the trade literature analyzing TBTs and SPS measures. The use of this type of trade barriers has been rising globally. We overcome the redundant component of the tariff equivalent of prohibitive technical barriers and the systematic lack of observed bilateral trade flow. We estimate the tariff equivalent of the barriers and compute the forgone trade effects associated with these prohibitive barriers. Prohibitive barriers inherently have a redundant component and forgone trade effects are difficult to compute.

We apply the approach to trade restrictions in apple trade. The rigorous investigation of the Australia–New Zealand apple dispute validates the approach. Importantly, our research raises policy implications. The tariff equivalent of the Australian SPS measures is high (around 99%)

and consumers prefer New Zealand apples to Australian apples, confirming previous findings on the premium quality of New Zealand apples. If all the Australian SPS measures were removed, the increase in New Zealand apple imports by Australia would be quite high. We provide an upper-bound estimate of the injury New Zealand could claim in a WTO dispute with Australia in terms of forgone apple exports to the latter country. Our estimate is an upper bound because of the caveats inherent to price-wedge techniques, and because some SPS measures are likely to survive the WTO panel ruling as it was the case in the US-Japan apple dispute (Foster, Calvin and Krissoff, 2008). Finally, the welfare analysis shows that it is optimal for Australia to eliminate its SPS policy on New Zealand apple imports even in the case of a significant fire blight contamination and under various domestic supply conditions, as Australian consumers' gains would largely outweigh producers' losses. Building on James and Anderson's findings, we cast another doubt on the soundness of some of the Australian SPS policies affecting food trade.

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Table 1. Estimation Results of Maximum Likelihood Estimation

Parameters	Estimate (Unit)	P-value
TBT	0.99	0.007
δ_{NZ}	2.21	<0.001
δ_{AU}	1.72	<0.001
δ_{Other}	3.94	<0.001
γ	$8.55*10^{-5}$ ($/(km*kg))	<0.001
η_{nz}	$2.4*10^{-6}$	0.57
η_{AU}	$1.3*10^{-6}$	0.77
η_{Other}	$8.6*10^{-6}$	0.13
Ω_{NZ}	0.05 (10^3 MT)	<0.001
Ω_{AU}	0.06 (10^3 MT)	<0.001
Ω_{Other}	0.89 (10^3 MT)	<0.001
$v'(AOG)$	56.21	<0.001

Table 2. Dollar Value of TBT Across Years and Changes in Australian imports of New Zealand apples after the TBT removal

Year	p_{NZ} ($/kg)	d (km)	*TBT*	*TBT*($/kg)	Increase in Australian Import of NZ apples [a] (10^3 MT)	Increase in Export Revenue of NZ apples (millions of US$)
2003	0.66	2676	99%	0.88	54.47 (17.81)	35.95
2004	0.80	2676	99%	1.01	49.06 (16.76)	39.25
2005	0.80	2676	99%	1.01	47.40 (15.14)	37.92

[a] The values are the mean of the change in import estimates and those values in the parentheses are standard errors of the estimates

Table 3. Welfare Changes from Elimination of TBT

Year	wp_{NZ} ($/kg)	Tariff	*TBT*	Without Disease Transmission			With Disease Transmission (20% reduction)		
				CV *(million $)*	ΔPS *(million $)*	*Net Welfare*[a] *(million $)*	*CV* *(million $)*	ΔPS *(million $)*	*Net Welfare* *(million $)*
2003	0.66	2%	99%	79.03[b] (22.78)	-25.29 (1.44)	54.69	63.37 (24.98)	-25.42 (1.45)	38.89
2004	0.80	2%	99%	64.67 (16.98)	-24.81 (1.66)	40.86	50.08 (18.45)	-24.70 (1.70)	26.82
2005	0.80	2%	99%	84.81 (24.07)	-29.86 (1.81)	55.97	68.21 (26.12)	-30.09 (1.90)	39.12

[a] The net welfare is $CV + \Delta PS +$ changes in tariff revenue; the latter revenue is relatively small.

[b] **The values are the mean of the welfare estimates and those values in the parentheses are standard errors of the estimates.**

Table 4. Welfare Changes from Elimination of TBT without Disease Transmission at Different Elasticity of Australian Apple Supply

Year	ω_S =0.2			ω_S =0.4		
	CV (*million $*)	ΔPS (*million $*)	*Net Welfare* (*million $*)	*CV* (*million $*)	ΔPS (*million $*)	*Net Welfare* (*million $*)
2003	82.55 (23.11)	-29.52 (1.61)	54.01	70.53 (20.79)	-21.70 (1.29)	49.73
2004	69.71 (17.30)	-28.92 (2.37)	41.79	61.06 (17.81)	-21.09 (1.20)	40.97
2005	86.08 (25.54)	-33.66 (2.15)	53.38	76.12 (25.10)	-26.95 (1.40)	40.93

Appendix to The Tariff Equivalent and Forgone Trade Effects of Prohibitive Technical Barriers to Trade
(To be posted on Agecon Search)

Appendix Table 1. Countries and Years Included in the Data Set

Australia	1990-2005
Bangladesh	1991-2004
Barbados	1998-2005
Belgium	2000-2004
Brunei Darussalam	1992-1998, 2001-2003
Cambodia	2000-2004
Canada	1991, 1993, 1995-2005
China	1993-1996, 1998-2005
Denmark	1990-1992, 1994-1995, 1997, 2000, 2002-2004
Finland	1990-1995, 1998-2002
France	1995-2005
French Polynesia	1996-2005
Germany	1991-2005
India	1999-2005
Indonesia	1990-2005
Ireland	1992-1994, 1997-1998, 2001-2004
Italy	1994-2005
Kiribati	1995-1997, 2005
Malaysia	1990-2005
Maldives	1998-2005
Mauritius	1993-2005
Mexico	1992-2005
Netherlands	1992-2005
New Zealand	1990-2005
Norway	1993-2005
Philippines	1996-2005
Portugal	1999-2005
Russian Federation	1996-2005
Saudi Arabia	1991-2005
Seychelles	1995-2005
Spain	1990-2005
Sri Lanka	1990-1994, 1999-2005
Sweden	1992-2005
Switzerland	1990, 1992, 1994, 1997-2005
Thailand	1990-1991, 1993-2004
Trinidad and Tobago	1999-2000, 2004-2005
United States	1991-2005
United Kingdom	1993-2005

Technical appendix on the methodology

(For reviewers only to and be posted on Agecon Search)

1.The log-likelihood function specification is (for observations i=1…N)

$$g^i_{NZ}(\mathrm{x,y,wp,d,t;TBT},\delta,\mathbf{\Omega},\gamma,\eta)= \ln\left[v'(AOG)(wp^i_{NZ}+\gamma d^i_{NZ})(1+t^i_{NZ}+TBT^i_{NZ})(x^i_{NZ}+\Omega_{NZ})\right]-\delta_{NZ}-\eta_{NZ}\mathrm{y}^i_{NZ}, \quad \text{(A1.1)}$$

$$g^i_{AU}(\mathrm{x,y,wp,d,t;TBT},\delta,\mathbf{\Omega},\gamma,\eta)= \ln\left[v'(AOG)(p^i_{AU}+\gamma d^i_{AU})(1+t^i_{AU}+TBT^i_{AU})(x^i_{AU}+\Omega_{AU})\right]-\delta_{AU}-\eta_{AU}\mathrm{y}^i_{AU}, \quad \text{(A1.2)}$$

$$g^i_{Other}(\mathrm{x,y,wp,d,t;TBT},\delta,\mathbf{\Omega},\gamma,\eta)= \ln\left[v'(AOG)(p^i_{Other}+\gamma d^i_{Other})(1+t^i_{Other}+TBT^i_{Other})(x^i_{Other}+\Omega_{AU})\right]-\delta_{Other}-\eta_{Other}\mathrm{y}^i_{Other}. \quad \text{(A1.3)}$$

For observations i=1…N, we have

$$X^i_{NZ}=\begin{cases}\phi(g^i_{NZ})*\left|J^i_{NZ}\right| & if\ x^i_{NZ}>0\\ \Phi(g^i_{NZ}) & if\ x^i_{NZ}=0\end{cases}, \quad \text{(A 2.1)}$$

$$X^i_{AU}=\begin{cases}\phi(g^i_{AU})*\left|J^i_{AU}\right| & if\ x^i_{AU}>0\\ \Phi(g^i_{AU}) & if\ x^i_{AU}=0\end{cases}, \quad \text{(A2.2)}$$

$$X^i_{Other}=\begin{cases}\phi(g^i_{Other})*\left|J^i_{Other}\right| & if\ x^i_{Other}>0\\ \Phi(g^i_{Other}) & if\ x^i_{Other}=0\end{cases}, \quad \text{(A2.3)}$$

where $\left|J^i_{NZ}\right|$ is the absolute value of the Jacobian for the transformation from g^i_{NZ} to x^i_{NZ}; $\left|J^i_{AU}\right|$ is the absolute value of the Jacobian for the transformation from g^i_{AU} to x^i_{AU}; $\left|J^i_{Other}\right|$ is the absolute value of the Jacobian for the transformation from g^i_{Other} to x^i_{Other}; ϕ is the density function of standard normal distribution; and Φ is the cumulative density function of standard normal distribution.

The log-likelihood function is

$$l=\sum_{i=1}^{N}\ln(X^i_{NZ}X^i_{AU}X^i_{Other}) \ . \quad \text{(A3)}$$

The program is run in *R* version 2.4.1. The package *mle* under the library *stats4* is used to estimate the maximum likelihood function defined by equations (A1-A3).

2. The algorithm to calculate the increase in imports $x_{NZ}^{(i,j)}$, producer surplus $PS^{(i,j)}$ and compensating variation $CV^{(i,j)}$ after the elimination of SPS measures is as follows in steps (1)-(4).

We define:

$$\alpha_{NZ}^{(i,j)} = \exp(\eta_{NZ}^{(i)} * y_{AU} + \delta_{NZ}^{(i)} + \varepsilon_{NZ}^{(j)}),$$
$$\alpha_{AU}^{(i,j)} = \exp(\eta_{AU}^{(i)} * y_{AU} + \delta_{AU}^{(i)} + \varepsilon_{AU}^{(j)}), \qquad \text{(A4)}$$
$$\alpha_{Other}^{(i,j)} = \exp(\eta_{Other}^{(i)} * y_{AU} + \delta_{Other}^{(i)} + \varepsilon_{Other}^{(j)}).$$

(1) Solve for the new Australian domestic price p_{AU}^{new} where demand equals supply of Australian apples:

$$X_{AUAU}^{(i,j)} = S_{AU}(p_{AU}^{new}, \upsilon^{new}) \qquad \text{(A5)}$$

where $x_{AUAU}^{(i,j)} = \dfrac{(I - AOG)\alpha_{AU}^{(i,j)} - p_{AU}^{new}\Omega_{AU}^{(i)}(\alpha_{NZ}^{(i,j)} + \alpha_{Other}^{(i,j)}) + \alpha_{AU}^{(i,j)}(\Omega_{NZ}^{(i)} p_{NZ} + \Omega_{Other}^{(i)} p_{Other})}{p_{AU}^{new}(\alpha_{NZ}^{(i,j)} + \alpha_{AU}^{(i,j)} + \alpha_{Other}^{(i,j)})}$

and $X_{AUAU}^{(i,j)} = x_{AUAU}^{(i,j)}$ * population , $S_{AU}(p_{AU}^{new}, \upsilon^{new})$ is defined in equation (13); ($I - AOG$) is Australian per capita expenditure on apples; and $\upsilon^{new} = \upsilon$ if there is no disease transmission and $\upsilon^{new} < \upsilon$ if there is disease transmission. Since there is no explicit solution, we used numerical bisection method to solve for p_{AU}^{new}. The bisection method is illustrated in the calculation of $\boldsymbol{CV}^{(i,j)}$.

(2) Calculate the increase in imports of NZ apples in Australia:

$$x_{NZAU}^{(i,j)} = \frac{(I - AOG)\alpha_{NZ}^{(i,j)} - p_{NZ}\Omega_{NZ}^{(i)}(\alpha_{AU}^{(i,j)} + \alpha_{Other}^{(i,j)}) + \alpha_{NZ}^{(i,j)}(p_{AU}^{new}\Omega_{AU}^{(i)} + p_{Other}\Omega_{Other}^{(i)})}{p_{NZ}(\alpha_{NZ}^{(i,j)} + \alpha_{AU}^{(i,j)} + \alpha_{Other}^{(i,j)})} \qquad \text{(A6)}$$

(3) Calculate the producers' surplus.

$$PS^{(i,j)} = \upsilon p_{AU}^{(1+\omega_s)} / (1+\omega_s) - \upsilon^{new} p_{AU}^{new(1+\omega_s)} / (1+\omega_s) \qquad \text{(A7)}$$

(4) Calculate the $\boldsymbol{CV}^{(i,j)}$ using numerical bisection method.

3. The numerical bisection method is a root finding algorithm. This algorithm repeatedly divides an interval in half and then selects the sub-interval in which a root exists. To solve for the $\boldsymbol{CV}^{(i,j)}$ in step (3) on page 19, the function we have is

$$\boldsymbol{f}(\boldsymbol{CV}^{(i,j)}(\mathbf{p}^0, \mathbf{p}^1, \boldsymbol{I}, \mathrm{y}; \boldsymbol{\mu}^{(i)}, \boldsymbol{\varepsilon}^{(j)})) = \boldsymbol{V}(\mathbf{p}^0, \boldsymbol{I}, \mathrm{y}; \boldsymbol{\mu}^{(i)}, \boldsymbol{\varepsilon}^{(j)}) -$$
$$\boldsymbol{V}(\mathbf{p}^1, \boldsymbol{I} - \boldsymbol{CV}^{(i,j)}(\mathbf{p}^0, \mathbf{p}^1, \boldsymbol{I}, \mathrm{y}; \boldsymbol{\mu}^{(i)}, \boldsymbol{\varepsilon}^{(j)}), \mathrm{y}; \boldsymbol{\mu}^{(i)}, \boldsymbol{\varepsilon}^{(j)}), \qquad \text{(A8)}$$

where $\boldsymbol{V}$ is the indirect utility function obtained from maximizing the utility function defined in equation (1) and $\boldsymbol{V}$ is nonlinear in $\boldsymbol{CV}^{(i,j)}$. There is no explicit solution to $\boldsymbol{f}(\boldsymbol{CV}^{(i,j)})=0$, therefore we use the numerical bisection method. The steps are as follows:

(1) Find the interval where the solution of $\boldsymbol{f}(\boldsymbol{CV}^{(i,j)})=0$ lies in. When there is no compensating variation, i.e., $\boldsymbol{CV}^{(i,j)}=0$, we have $\boldsymbol{f}(0)>0$; find a $\boldsymbol{CV}_{\max}{}^{(i,j)}$, where $\boldsymbol{f}(\boldsymbol{CV}_{\max}{}^{(i,j)})<0$. $\boldsymbol{CV}_{\max}{}^{(i,j)}$ is generally set to be a large value. Then the first interval is $[0, \boldsymbol{CV}_{\max}{}^{(i,j)}]$, and we have $\boldsymbol{f}(0)*\boldsymbol{f}(\boldsymbol{CV}_{\max}{}^{(i,j)})<0$;

(2) Divide the interval in two by computing $c=0.5*(0+\boldsymbol{CV}_{\max}{}^{(i,j)})=0.5\boldsymbol{CV}_{\max}{}^{(i,j)}$. The two intervals are $[0,c]$ and $[c, \boldsymbol{CV}_{\max}{}^{(i,j)}]$. There are two possibilities: either $\boldsymbol{f}(0)*\boldsymbol{f}(c)<0$ or $\boldsymbol{f}(c)*\boldsymbol{f}(\boldsymbol{CV}_{\max}{}^{(i,j)})<0$; if $\boldsymbol{f}(0)*\boldsymbol{f}(c)<0$, then the next sub-interval where the root lies in is $[0,c]$, otherwise if $\boldsymbol{f}(c)*\boldsymbol{f}(\boldsymbol{CV}_{\max}{}^{(i,j)})<0$ then the next sub-interval where the root lies in is $[c, \boldsymbol{CV}_{\max}{}^{(i,j)}]$.

(3) Repeat (4.2) to the sub-intervals with $\boldsymbol{f}(x)$ having opposite signs until the length of the interval is less than the tolerance level set. The solution is approximated by the mid point of the last sub-interval before the tolerance level is reached.