AgInfomatics

The Value of Neonicotinoids in North American Agriculture:

An Economic Assessment of the Benefits of Nitroguanidine Neonicotinoid Insecticides in the United States and Canada

2015

This report series, researched and produced by AgInfomatics, LLC, is a comprehensive analysis of the economic and societal benefits of nitroguanidine neonicotinoid insecticides in North America. The research was sponsored by Bayer CropScience, Syngenta and Valent in support of regulatory review processes in the United States and Canada, with Mitsui providing additional support for the turf and ornamental studies.

AgInfomatics, an agricultural consulting firm established in 1995 by professors from the University of Wisconsin-Madison and Washington State University, conducted independent analyses exploring the answer to the question: *What would happen if neonicotinoids were no longer available?* Comparing that answer to current product use revealed the value of neonicotinoids.

Robust quantitative and qualitative study methods included econometrics modeling of insecticide use, crop yield data and market impacts; surveys of growers, professional applicators and consumers; regional listening panel sessions; and in-depth case studies.

Active ingredients in the study included clothianidin, dinotefuran, imidacloprid and thiamethoxam.

The Value of Neonicotinoids in North American Agriculture

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Estimated Impact of Neonicotinoid Insecticides on Pest Management Practices and Costs for U.S. Corn, Soybean, Wheat, Cotton and Sorghum Farmers

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A Case Study of Neonicotinoid Use for Controlling Silverleaf Whitefly in Ornamentals

Executive Summary

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Executive Summary

This report summarizes the methods and results for a market-level assessment of the economic benefits of neonicotinoid insecticides for key crops in the U.S. and Canada. U.S. crops examined include corn, soybean, wheat, cotton and sorghum, plus processed tomato, fresh tomato, and potato; Canadian crops examined include canola, corn and soybean.

The approach first uses supply and demand functions for each crop, either based on an existing economic modeling system (U.S. corn, soybean, wheat, cotton and sorghum) or estimated using historical data (processed tomato, fresh tomato, and potato in the U.S. and canola, corn and soybean in Canada). Second, the analysis models how the market supply curve for each crop would shift if neonicotinoid insecticides were not available. For this non-neonicotinoid scenario, the analysis focuses on two impacts: an increase in the cost of production and a decrease in per acre yields. Estimated cost increases were as reported by Mitchell (2014a, 2014b) or developed as described here, while yield decreases were as reported by Mitchell (2014c). Third, the analysis uses the change in economic surplus (the sum of consumer and producer surplus changes) between the baseline and the non-neonicotinoid scenario. The decrease in economic surplus when changing from the baseline to this non-neonicotinoid scenario measures the economic losses that would occur if neonicotinoid insecticides were no longer available. This economic loss also measures the market-level benefits of neonicotinoid insecticides – the estimated economic gain to society that would occur when moving from the non-neonicotinoid scenario to the baseline.

Economic benefits estimated in this manner are not the same as the short-term economic costs if neonicotinoid insecticides were no longer available. In the immediate-term, the cost and yield effects used in this analysis would reduce farmer income. Multiplying the percentage yield losses by average per acre yields and total treated acres and market prices would give the total value of these yield losses, while multiplying the per acre cost increases by total treated acres would give the aggregate cost increase. These avoided farmer losses are a short-term estimate of the benefits of neonicotinoid insecticides. However, the estimated economic benefits reported here are not estimates of this sort. Rather, the estimates here assume prices and total production re-equilibrate via market processes over the medium- or longer-term – prices change, and farmers reallocate crop acreages in response to the changes in relative profitability. Furthermore, the estimates here not only capture the effects on producer income but also consumer benefits.

The aggregate economic benefit of neonicotinoid insecticides estimated in this manner ranges from $4.0 to $4.3 billion annually in the U.S. and $150 million to $275 million in Canada. Consumers capture most of these benefits as reduced food prices, especially for meat, dairy and eggs, and to some extent biofuel production. Without neonicotinoid insecticides, estimated equilibrium corn prices would increase about $0.25/bu, wheat prices about $0.22/bu and sorghum price by about $0.18/bu, while in Canada, equilibrium canola prices would increase from $32/mt to $64/mt. Estimated total cropped acres in the U.S. would also increase total cropped acres in the U.S. would increase about 340,000 to 410,000 acres by converting land from non-crop uses, with 225,000 to 265,000 of these acres coming from land enrolled in the Conservation Reserve Program, a program that removes highly erodible and otherwise environmentally sensitive land from crop production.

1.0 Introduction

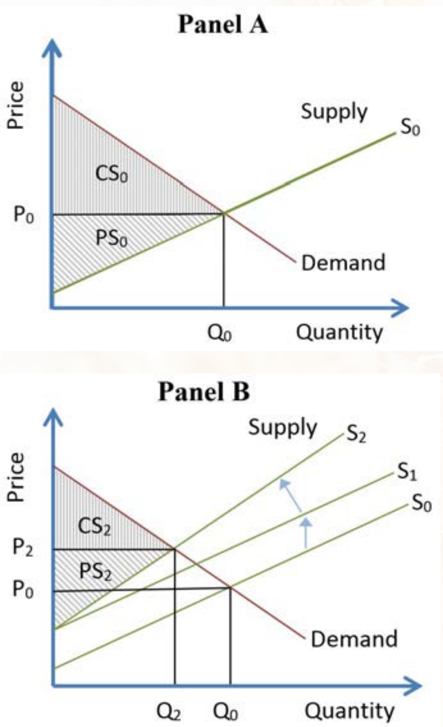
This report summarizes the assessment of the market-level benefits of nitro-guanidine neonicotinoid insecticides to the U.S. and Canadian economies from their use on corn, soybean, wheat, cotton, sorghum, potato and to-mato in the U.S. and canola, corn and soybean in Canada. In this report, the term neonicotinoid is used for the following active ingredients: clothianidin, dinotefuran, imidacloprid and thiamethoxam, which are the nitroguanidine neonicotinoid insecticides, as opposed to the cyano-amidine neonicotinoid insecticides such as acetamiprid. This report first describes the general conceptual framework used to estimate the market-level benefits of neo-nicotinoids and then presents the specific data and methods used for the crops analyzed. Finally, the results are presented and discussed.

2.0 Conceptual Framework

This section provides a brief overview of the conceptual model underlying the economic analysis to better allow readers to understand the process and results. The key underlying economic concept is 'surplus.' Consumer surplus is generated when consumers are paying less for a good than their maximum willingness to pay. For example, paying \$2 for an apple, when you were willing to pay as much as \$3 for the apple, generates \$3 – \$2 = \$1 of consumer surplus. The same concept holds from the producer side – selling an apple for \$2, when you were willing to sell the apple for \$0.50, generates \$2 – \$0.50 = \$1.50 of producer surplus. From a market-level per-spective, which integrates and aggregates over all consumers and produc-ers and all possible prices and quantities, the demand curve traces out the maximum consumer willingness to pay for a good, while the supply curve traces out the minimum willingness to accept to sell a good. Market equi-librium occurs at the price and quantity at which supply equals demand, so that the area above this equilibrium price and below the demand curve out to the equilibrium quantity is consumer surplus, while the area below this equilibrium price and above the supply curve out to the equilibrium quan-tity is producer surplus. Both of these areas are dollar value measures of the aggregate surplus that producers and consumers derive in the market at the equilibrium price and quantity (P_0 and Q_0). These areas (PS_0 = initial producer surplus and CS_0 = initial consumer surplus) are illustrated in Panel A of Figure 1, assuming linear supply and demand curves (i.e., first-order approximations of the 'true' curves).

Counterfactual approaches are commonly used to estimate the economic benefits of specific technologies and are often used in policy analysis (e.g., Falck-Zepeda et al. 2000; Mitchell 2014d; Moschini et al. 2000; Price et al. 2003). The process develops a hypothetical (counterfactual) scenario with-out the technology and then examines the differences between the original situation and this counterfactual scenario to determine the benefits of the technology. For a market-level economic assessment of the benefits of a technology, the process focuses on how the supply and/or demand curves change without the technology, then estimates changes in consumer and producer surplus to measure the economic benefits of the technology. Oth-er types of benefits are not estimated by this process, but the process does provide a useful way to aggregate impacts occurring at the consumer and/

Figure 1. Producer and consumer surplus in a market (Panel A), and how a producer cost increase and yield decrease change supply and producer and consumer surplus (Panel B).



or producer level in a way that incorporates price adjustments that occur at the market level.

To estimate the economic benefits of neonicotinoid insecticides, this counterfactual process focuses on crops that use the insecticides and changes in their supply curve that would occur if neonicotinoid insecticides were not available. More specifically, a non-neonicotinoid scenario is developed that estimates how farmer costs and yields would change if they did not have neonicotinoid insecticides and then estimates the implied changes in the crop supply function and in consumer and producer surplus. Figure 1 illustrates this process conceptually.

In Figure 1, Panel A illustrates the original market situation for a crop when neonicotinoid insecticides are available, while Panel B illustrates the situation for the same market after cost and yield changes have occurred for farmers as a result of the non-neonicotinoid scenario. An increase in the cost of production under the non-neonicotinoid scenario implies a contraction or upward shift of the supply curve – farmers would need a higher price to sell any given quantity to compensate for the increase in cost. With a linear supply curve, this cost change implies a parallel upward shift in the supply curve, from S_0 to S_1 in Panel B. Similarly, a decrease in per acre yield for the crop under the non-neonicotinoid scenario also implies a contraction or upward shift of the supply curve – farmers would again need a higher price to sell any given quantity since more acres would be needed to generate the same level of production. With a linear supply curve and a constant percentage decrease in per acre yields, this change implies an upward twist of the supply curve, from S_1 to S_2 in Panel B. The final equilibrium for the non-neonicotinoid scenario generates producer and consumer surplus of PS_2 and CS_2 in Panel B. Based on this new equilibrium, the benefit of neonicotinoid insecticides for consumers of this crop is the change in consumer surplus: $CS_2 – CS_0$, i.e., without neonicotinoids, consumer surplus would decrease to CS_2 from its original level of CS_0. Similarly, the benefit of neonicotinoid insecticides for producers of this crop is the change in producer surplus: $PS_2 – PS_0$. The net change in social welfare is then the sum of the net change in producer and consumer surplus or $PS_2 – PS_0 + CS_2 – CS_0 = PS_2 + CS_2 – (PS_0 + CS_0)$.

The concepts of consumer and producer surplus illustrated in Figure 1 are the foundation of the economic analysis, with additional complexities then added to this basic framework. For example, the Appendix graphically illustrates how the partial equilibrium framework changes once international trade is added. The essence of the model remains the same, but the domestic market has excess supply that is exported, and the market for the rest of the world (ROW) has excess demand that is imported from the domestic market. There is a single equilibrium price that sets total supply equal to total demand and exports equal to imports, but there is still a single crop and a single aggregate (global) market for this crop.

The key for empirical analysis is estimating supply and demand functions for each crop in each market and the impact of neonicotinoids on farmer costs of production and yields. An important issue is whether or not the estimated supply and demand functions for a crop depend on the prices, acreage and similar factors for related crops. A partial equilibrium analysis examines each crop in isolation, with supply and demand equations that do not depend on prices, acreages or similar factors for related crops. This is the type of analysis illustrated in Figure 1 and in the Appendix. With international trade, there may be two markets (domestic and ROW), but there is still a single crop and a single aggregate (global) market for this crop. On the other hand, a multi-market equilibrium analysis allows crop markets to interact, so that the supply for one crop impacts equilibrium prices and quantities for other related crops.

In the case of neonicotinoid insecticides, a partial equilibrium analysis indicates the distribution of benefits among producers and consumers, but the analysis is limited in that it allows price changes to occur only for the crop under consideration. Each crop market is analyzed in isolation, without interactions with other crop markets, on an intermediate time scale, after the market for the crop equilibrates but before the changes have worked their way through related crop markets. A multi-market equilibrium analysis does not examine each crop in isolation but models simultaneous changes in costs and crop yields for multiple crops, then shifts crop acreages and prices as farmers seek more profitable crop allocations until prices and acreages settle on a long-run equilibrium. This re-equilibration process can even impact crop acreages and prices for crops not directly affected by the policy examined. Furthermore, these models can incorporate international trade into the analysis. Multi-market equilibrium models provide the most comprehensive assessments but are resource intensive and require regular updating to remain current, and so such models can be limited in their scope.

Partial equilibrium analysis is widely used. For example, Soliman et al. (2012) provides a well-written example of how to use partial equilibrium analysis, using it to examine the economic impact of the pine wood nematode in Europe. Partial equilibrium analysis has been used for decades to estimate the economic benefits of new agricultural technologies in developing nations (e.g., Evanson and Flores 1978; Scobie and Posada 1978; plus Tsakok's (1990) 'practioner's guide'). The method has also been used to examine social returns to investment on public research in agriculture, with several technical improvements or alternatives developed (e.g., see Alston et al.'s (1995) widely cited book). More recently, it has been used to estimate the value of various biotech crops (e.g. Falck-Zepeda et al. 2000; Moschini et al. 2000; Price et al. 2003).

The major difficulty for a multi-market equilibrium analysis is developing the multi-market equilibrium model to use to conduct the analysis. The econometrics to estimate the interrelated supply and demand equations and programming the interface and simulations to identify the long run equilibrium can be intensive. However, once such a model is developed, it can be used for a variety of analyses. This project uses the existing AGSIM model (Taylor 1993), which has a long history and has been used by both academics and government analysts and regulators to analyze a wide variety of agricultural policies, including several pertaining to pesticides (e.g., Carlson 1998; Mitchell 2014d; Ribaudo and Hurley 1997; Szmedra 1997; Taylor et al. 1991; White et al. 1995). AGSIM was updated by its developer, Dr. Robert Taylor, specifically for this analysis.

The analysis reported here uses AGSIM to estimate the benefits of neonicotinoid insecticides for corn, soybeans, wheat, cotton and sorghum and includes international trade. Because a multi-market model comparable to AGSIM is not available for key Canadian crops or U.S. specialty crops, partial equilibrium analysis with trade is used for these crops. This report presents results for U.S. potato and tomato, and Canadian canola, corn and soybeans. The next section of this report describes the data and methods used to parameterize and/or estimate supply and demand models for the analysis.

3.0 Data and Methods

Empirical implementation of the analysis to estimate the economic benefits of neonicotinoid insecticides requires supply and demand equations for the crop markets examined, plus the yield and cost changes implied by the non-neonicotinoid scenario. This report uses AGSIM as a multi-market equilibrium model to estimate the benefits of neonicotinoids for corn, soybean, wheat, cotton and sorghum in the U.S. However, a partial equilibrium approach is used to estimate benefits for U.S. fresh and processed tomatoes and potatoes, as well as for Canadian canola, corn and soybean, since an equivalent model to AGSIM is not available for these specialty crops or these Canadian crops.

AGSIM already contains estimates of supply and demand equations for current crop markets, so the description here instead provides an overview of AGSIM. However, for the other crops examined using a partial equilibrium approach, this report summarizes the conceptual framework, data and estimation results for supply and demand equations used in the partial equilibrium analysis.

3.1 AGSIM overview

AGSIM is an econometric model of supply and demand for U.S. crop production that estimates changes in producer and consumer surplus for different policy scenarios. AGSIM also incorporates international trade for the modeled crops. Taylor (1993) provides a detailed description of AGSIM, and the model is regularly updated to examine new agricultural issues, with the most recent update specifically for this project. AGSIM models crop supply and demand, as well as crop prices, land allocation and net exports for ten major crops: corn, soybeans, wheat, cotton and sorghum, as well as barley, oats, peanuts, rice and hay, plus land enrolled in the conservation reserve program (CRP).

Analyzing policies with AGSIM requires specifying the effect of each policy on average yields and per acre costs. Based on these yield and cost effects, AGSIM determines the national market price for each crop, as well as total production and planted area for each crop, after markets and planted areas have moved to a new equilibrium in response to the policy scenario. Differences between scenarios estimate how each policy affects equilibrium prices, production and planted area for each crop. Based on these results, AGSIM determines impacts on producer income by crop and consumer surplus by crop and by major end use.

AGSIM has a long history and has been used to analyze a variety of agricultural policies by both academics and government analysts (Taylor 1993).

TECHSIM, an early predecessor of AGSIM, was used to examine the economics of the loss of pesticides and other pesticide regulatory issues (Osteen and Kuchler 1986, 1987; Osteen and Suguiyama 1988). Dinan et al. (1988, 1991) used AGSIM to analyze the impact of the United States Environmental Protection Agency's (EPA) environmental regulations more broadly. AGSIM has been used to examine aggregate economic impacts of federal commodity price supports, CRP lands returning to crop production and pesticide use reductions (Taylor 1994; Taylor et al. 1991, 1994), plus to estimate the economic benefits of atrazine and other herbicides (Carlson 1998; Mitchell 2014d; Ribaudo and Hurley 1997; Szmedra et al. 1997; White et al. 1995). The EPA has also used AGSIM to estimate the costs of air pollution regulation and for an atrazine benefits assessment (U.S. EPA 1997, 2002). Given its long history of use by academics and by United States Department of Agriculture (USDA) and EPA analysts, AGSIM is well-suited for estimating the benefits of neonicotinoid insecticides in the U.S.

3.2 Partial equilibrium analysis

3.2.1 Analytical framework

For the crops analyzed using a partial equilibrium framework for this report, the supply and demand equations are set up in a general linear form:

$$Q_S = a_0 + a_1 X_1 + a_2 X_2 + \dots + aP + e_S$$
$$Q_D = b_0 + b_1 Z_1 + b_2 Z_2 + \dots + bP + e_D \qquad (1)$$

where Q_S and Q_D are the respective supply and demand of the crop; P is the crop price; X_1, X_2, … and Z_1, Z_2, … are other variables that respectively impact supply and demand, such as fertilizer cost and consumer income; a_0, a_1, .., b_0, b_1, …, a, and b are parameters to estimate; and are estimation errors. The supply and demand equations as specified in equation (1) are both linear in price. To simplify the derivation below but not affect the analysis, define and , so that $Q_S = A + aP$ and $Q_D = B + bP$.

The counterfactual non-neonicotinoid scenario has two effects on production: it changes the cost of production and yield per acre. These changes then both affect the supply curve as illustrated in Panel B of Figure 1. For this analysis, the cost of production change for the non-neonicotinoid scenario will be expressed as a dollar change per unit of crop output relative to the original neonicotinoid case, while the yield change for the non-neonicotinoid scenario will be expressed as a percentage change in yield relative to the original neonicotinoid case.

The new supply function with a cost change per unit of crop output, k, can be expressed as $Qs = A + a(P+k) = A + ak + aP$.

Based on this equation, the new supply function with both a cost change per unit of crop output, k, and a yield percentage change, L, can be expressed as

$$Q_S = A + ak + a(1+L)P \qquad (2).$$

Based on equation (2), the system of supply and demand functions for the domestic market and the rest of the world (ROW) for the non-neonicotinoid scenario are as follows:

Domestic supply: $Q_S = A + ak + a(1+L)P$

Domestic demand: $Q_D = B - bP$

ROW supply: $Q_{RS} = C + cP$

ROW demand: $Q_{RD} = D - dP$

Solve this system for the equilibrium price P by setting $Q_S + Q_{RS} = Q_D + Q_{RD}$ and substituting in the equations from above to obtain (see Appendix for additional details)

$$P = \frac{B + D - A - ak - C}{a(1+L) + c + b + d} \quad (3)$$

Setting $k = 0$ and $L = 0$ in equation (3) gives P_0, the equilibrium price for the original case:

$$P_0 = \frac{B + D - A - C}{a + c + b + d}$$

Based on this definition of P_0, the new equilibrium price P_1 for the non-neonicotinoid counterfactual scenario can be written as:

$$P_1 = \frac{P_0(a + c + b + d) - ak}{a(1+L) + c + b + d}$$

Next we derive an expression for the percentage reduction in price in terms of elasticities. Define $K = k/P_0$, so that $k = KP_0$, where K is the cost change per unit of crop output as a proportion of the original price. Using the definitions of P_0 and P_1, the percentage reduction in price,

$Z = -\frac{P_1 - P_0}{P_0}$, can be expressed as (see Appendix for additional details):

$$Z = \frac{K\varepsilon + L\varepsilon}{\varepsilon(1+L) + \eta_{RED}(1-s) + \eta_D s} \quad (4)$$

Here is the domestic supply elasticity at (P_0, Q_0): $\varepsilon = \frac{\partial Q_S}{\partial P}\frac{P_0}{Q_0}$; η_D is the absolute value of the domestic demand elasticity at (P_0, Q_0): $\eta_D = \left|\frac{\partial Q_D}{\partial P}\frac{P_0}{Q_0}\right|$; η_{RED} is the absolute value of the ROW excess demand elasticity at (P_0, Q_0):

$\eta_{RED} = \left|\frac{\partial(Q_{RD,0} - Q_{RS,0})}{\partial P}\frac{P_0}{Q_{RD,0} - Q_{RS,0}}\right| = \left|\frac{\partial Q_{T,0}}{\partial P}\frac{P_0}{Q_{T,0}}\right|$; and s is the share of production consumed domestically at (P_0, Q_0): $s = \frac{Q_{D,0}}{Q_{S,0}}$.

Next, using this expression for Z and the other definitions above, we derive equations for the change in consumer surplus, the change in producer income and total welfare for the ROW for the non-neonicotinoid counterfactual scenario relative to the original case with neonicotinoids. The Appendix provides more complete step-by-step derivations for equations (5)-(7). The change in consumer surplus can be expressed as:

$$\Delta CS = P_0 Q_{D,0} Z(1 + 0.5Z\eta_D) \quad (5)$$

Similarly, the change in producer surplus can be expressed as:

$$\Delta PS = \begin{matrix} P_0 Q_{S,0}(K - Z) + 0.5P_0 Q_{S,0}(1 - K - \frac{1-K}{1+L}) \\ + \ 0.5P_0 Q_{S,0}(-Z + 1 - \frac{1-K}{1+L})\varepsilon[-Z + L(1-Z) + K] \end{matrix} \quad (6)$$

And finally, the change in total welfare for the ROW (the sum of consumer and producer surplus) can be expressed as:

$$\Delta TS = ZP_0 Q_{T,0}(1 + 0.5Z\eta_{RED}) \quad (7)$$

Equations (5)-(7) are the final equations used in the partial equilibrium analysis to estimate changes in domestic consumer surplus, producer income and in the ROW welfare for the non-neonicotinoid scenario relative to the original case with neonicotinoids available. The next section describes the data used to implement these equations for fresh tomatoes, processed tomatoes and potatoes (all uses combined) in the U.S. and for Canadian canola, corn and soybean.

3.2.2 Data and elasticity estimates

Equations (5)-(7) are expressions for the changes in domestic consumer surplus, producer income and the impact on the ROW welfare in terms of three types of parameters a) the original price, quantity produced and domestic consumption (P_0, $Q_{S,0}$ *and* Q_{D0}), b) domestic supply and demand elasticities, and the ROW excess demand elasticity (ε, η_D and η_{RED}) and c) cost and yield impacts of the non-neonicotinoid counterfactual scenario (*k* and L). For the analysis reported here, data for crop prices, quantities sold and net exports are available from public sources (USDA-ERS 2013, National Potato Council 2014; Statistics Canada 2014), the required elasticities are estimated using historical data, and the per acre cost and yield impacts of the non-neonicotinoid scenario are from previous project reports (Mitchell 2014a; Mitchell 2014b; Mitchell 2014c).

Table 1 reports the initial price and domestic production, and consumption data used for the partial equilibrium analysis for fresh tomatoes, processed tomatoes and potatoes in the U.S. and for canola, corn and soybean in Canada. Data for the 2012 season was used for each crop, with the tomato data from USDA-ERS (2013), potato data from the National Potato Council (NPC 2014) and data for the Canadian crops from Statistics Canada (2014).

Table 1. Initial price and domestic production and consumption and regression estimated elasticities used for the partial equilibrium analysis.

Nation	Crop	Parameter	Value[a]	Elasticity	Estimate
USA	Fresh Tomato	Initial Price P_0	\$31.30/cwt	Supply ε	0.100
		Domestic Production $Q_{S,0}$	32.57 million cwt	Demand	-0.080
		Domestic Demand $Q_{D,0}$	63.76 million cwt	ROW Excess Supply	1.513
USA	Processed Tomato	Initial Price P_0	\$3.84/cwt	Supply ε	0.263
		Domestic Production $Q_{S,0}$	263.57 million cwt	Demand	-0.300
		Domestic Demand $Q_{D,0}$	209.09 million cwt	ROW Excess Demand	-1.557
USA	Potato	Initial Price P_0	\$9.41/cwt	Supply ε	0.286
		Domestic Production $Q_{S,0}$	429.65 million cwt	Demand	-0.351
		Domestic Demand $Q_{D,0}$	397.75 million cwt	ROW Excess Demand	-0.227
Canada	Canola	Initial Price P_0	\$462.76/mt	Supply ε	0.255
		Domestic Production $Q_{S,0}$	17.97 million mt	Demand	-0.128
		Domestic Demand $Q_{D,0}$	7.24 million mt	ROW Excess Demand	-0.083
Canada	Corn[b]	Initial Price P_0	\$230.16/mt	Supply ε	0.170
		Domestic Production $Q_{S,0}$	11.36 million mt	Demand	-0.133
		Domestic Demand $Q_{D,0}$	11.68 million mt	ROW Excess Supply	0.677
Canada	Soybean	Initial Price P_0	\$487.60/mt	Supply ε	0.269
		Domestic Production $Q_{S,0}$	5.20 million mt	Demand	-0.457
		Domestic Demand $Q_{D,0}$	1.94 million mt	ROW Excess Demand	-0.093

[a] Sources: tomato data from USDA-ERS (2014), potato data from NPC (2014), and Canadian data from CANSIM (2014).

[b] Canada was a net importer of corn until 2012/13, so the estimated ROW corn excess supply elasticity is based on data from 1989/90 to 2011/12.

The supply and demand elasticities are estimated for U.S. fresh tomatoes, processed tomatoes and potatoes (all uses combined) using national-level price and quantity data for 1970-2012 for both types of tomatoes and 1975-2011 for potatoes (USDA-ERS 2012; National Potato Council 2014). The supply and demand elasticities are estimated for Canadian canola, corn and soybeans using national level price and quantity data for 1989-2013 (Statistics Canada 2014). As the U.S. is a net importer of fresh tomatoes and Canada has been a net importer of corn, the ROW excess supply elasticity is estimated rather than the ROW excess demand elasticity, but as the definition of indicates, both are the elasticity of the trade quantity with respect to price.

Supply and demand equations are specified in double-log form so that they are linear in the variables as reported in equation (1)[1] and so that the estimated coefficients are the required elasticities. The regressions are estimated in SAS, version 9.4 (SAS Institute, Cary, NC), as single-equation (reduced form) regressions. Table 1 also reports the estimated elasticities used for each crop for the benefit analysis, showing that all estimated supply and demand elasticities have their own price effects consistent with economic theory (i.e., downward sloping demand and upward sloping supply in each

[1] The estimated equations have the same form as equation (1), except the variables are $\ln(Q_S)$, $ln(Q_D)$, $ln(P)$, $ln(X_i)$ and $ln(Z_i)$, rather than Q_S, Q_D, P, X_i and Z_i.

crop's own price). The Appendix reports full estimation results for each crop, including the estimated coefficients/elasticities, standard errors and p values, and goodness of fit measures.

For the crops analyzed using a partial equilibrium approach, the initial market conditions (Q_0 *and* P_0) are taken from publicly available data as reported in Table 1, and the elasticities were estimated, with the estimates reported in Table 1. Given this information, equation (4) is used to calculate the percentage change in price (Z), and then equations (5)-(7) are used to calculate changes in U.S. consumer and producer surplus and in the ROW total surplus. For the crops modeled by AGSIM, the system already has the initial market conditions and estimated supply and demand equations built in and the system generates the estimated changes in producer and consumer surplus as model output. Given this process for partial equilibrium analysis and the AGSIM model for commodity crops, all that remains to implement these two approaches is the impact of the non-neonicotinoid scenario on the cost of production and yields (k *and* L).

3.3 Cost impacts

Mitchell (2014a, 2014b) describes the data and process used to estimate the impact of the non-neonicotinoid scenario on cost of production for corn, soybean, wheat, cotton and sorghum in U.S. production systems. Table 2 reports these cost impacts as the average cost increase in dollars per planted acre for these crops based on Table 11 in Mitchell (2014a). Across these five crops, the cost increase totals $848 million annually, with about 80 percent of this total cost impact falling on corn (Figure 5 in Mitchell 2014a). Costs per neonicotinoid base acre range from $10.39 for sorghum to $1.97 for spring wheat. Higher costs occur for sorghum and corn due to switching to higher cost active ingredients and increases in application costs. However, once these costs are spread over all planted acres (i.e., not just those currently treated with neonicotinoids), the average cost changes per planted acre range from $7.40 for corn to $0.50 for wheat, as reported in Table 2.

A cost analysis comparable to Mitchell (2014a, 2014b) was not completed for U.S. processed tomatoes, fresh tomatoes and potatoes. For this partial budget analysis, crop budgets were used for processed tomatoes in California (Miyao et al. 2007a, 2007b, 2008), fresh tomatoes in Florida (Hewitt 2006; VanSickle et al. 2009) and potatoes in Idaho (Patterson 2012). These itemized budgets included costs for insect control that were adjusted to the 2010-2012 average using the Producer Price Index available in the March issue of Agricultural Prices published by USDA-NASS.[2] Based on comments at grower listening sessions of large cost impacts if neonicotinoid insecticides were not available (Shaw and Genskow 2014), a low cost and a high cost scenario were developed assuming a 10 percent and a 20 percent increase in insecticide costs, which was averaged across all budgets for each crop. The resulting cost increases after conversion to 2010-2012 averages are reported in Table 2. Insecticide costs are quite high for fresh tomatoes, so that 10 percent and 20 percent cost increases imply a $50 and $100 cost increase per acre, respectively. Comparable cost increases for potato are slightly lower, at almost $33 and $66 per acre but quite modest for processed tomato at $3.44 and $6.88 per acre.

[2] Online: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1002.

Table 2. Average cost increases used for the non-neonicotinoid scenario.

Crop	Nation	**Cost** ($ per Treated Acre) Low	High	% Planted Acres Treated	**Cost** ($ per Planted Acre) Low	High
Corn	USA	8.32[a]		88.9%	7.40[a]	
Cotton	USA	2.21[a]		65.3%	1.44[a]	
Potato	USA	32.80	65.60	34.7%	11.38	22.76
Sorghum	USA	10.39[a]		43.1%	4.48[a]	
Soybean	USA	3.30[a]		39.8%	1.31[a]	
Tomato: Fresh	USA	50.20	100.40	62.2%	31.22	62.45
Tomato: Processed	USA	3.44	6.88	62.2%	2.14	4.28
Wheat	USA	2.46[a]		20.0%	0.49[a]	
Canola	Canada	3.30[b]		87.2%	2.88[b]	
Corn	Canada	8.32[c]		75.1%	6.25[c]	
Soybean	Canada	3.30[b]		66.2%	2.18[b]	

[a] Only one cost scenario developed.
[b] No data, so same as U.S. soybean; only one cost scenario developed.
[c] No data, so same as U.S. corn; only one cost scenario developed.

A cost analysis comparable to Mitchell (2014a; 2014b) was also not completed for canola, corn and soybeans in Canada due to the lack of required data, and so for this partial budget analysis, U.S. costs were used. Specifically, for Canadian corn and soybean, the U.S. cost increase per neonicotinoid treated acre was used (i.e., $8.32 and $3.30 per acre for corn and soybean respectively), while for Canadian canola, the same cost increase as for U.S. soybean was used (i.e., also $3.30 per acre). These costs were then multiplied by the percentage of planted acres treated with neonicotinoids for canola, corn and soybean as reported in Tables 12-14 of Hurley and Mitchell (2014) to give the cost increase per planted acre as reported in Table 2. Note that these cost changes are then expressed in terms of U.S. dollars, not Canadian dollars. Throughout this analysis, U.S. dollars are used and when needed, the conversion factor used was 0.92 U.S. dollars per Canadian dollar.

Because AGSIM parameterizes scenarios using cost changes as dollars per planted acre, AGSIM uses the cost changes for U.S. corn, soybean, wheat, cotton and sorghum as reported in Table 2. However, the partial equilibrium analysis parametrizes the cost change for the analysis as dollars per unit of crop output (k), and so the cost changes for potato, tomato and the Canadian crops in Table 2 are divided by average yields per acre for the base year, calculated by dividing production in Table 1 ($Q_{S,0}$) by total planted acres.

3.4 Yield impacts

Mitchell (2014c) describes the data and process used to analyze the extensive data from more than 1,500 small plot field studies to estimate the yield benefits of neonicotinoid insecticides for the crops examined in this economic analysis. The estimated yield benefits in Tables 2 and 3 of Mitchell (2014c) are the average percentage yield increases for neonicotinoid insecticide treatments relative to untreated controls or to alternative, non-neonicotinoid insecticide treatments. These neonicotinoid yield benefits relative to non-neonicotinoid alternatives are the data-derived yield losses for the non-neonicotinoid scenario – the average percentage decrease in yields when using non-neonicotinoid alternatives rather than neonicotinoids. The process used to derive the yield losses used for the non-neonicotinoid scenario is described next for each crop in Table 3.

For U.S. cotton, sorghum and potato, a single yield loss scenario is developed using the reported yield benefits for a neonicotinoid insecticide relative to a non-neonicotinoid insecticide as reported in Table 3 of Mitchell (2014c). A single yield loss scenario is used because there were no Canadian data analyzed for these crops by Mitchell (2014c). However, for other crops, low and high yield loss scenarios are developed that use only the U.S. or only the Canadian observations, or all the observations.

For U.S. corn, the reported yield benefits for a neonicotinoid insecticide relative to a non-neonicotinoid insecticide are used as reported in Table 3 of Mitchell (2014c). The low yield loss scenario uses the average benefit reported for the U.S. observations, while the high loss scenario uses the average benefit reported for all observations. However, for Canadian corn, the low yield loss scenario uses the average benefit reported for all observations, while the high loss scenario uses the average benefit reported for the Canadian observations. The assumptions are essentially the same for Canadian canola – the low yield loss scenario uses the average benefit reported for all observations in Table 3 of Mitchell (2014c) for a neonicotinoid insecticide relative to a non-neonicotinoid insecticide, while the high loss scenario uses the average benefit reported for the Canadian observations.

In the U.S. and Canada, soybean and wheat growers do not have practical, effective non-neonicotinoid alternative insecticides for use to manage soil-dwelling pests, such as wireworms, seed maggots and grubs (Mitchell 2014b). As a result, the low and high yield loss scenarios use a weighted average of the yield benefits for a neonicotinoid insecticide relative to a non-neonicotinoid insecticide and relative to no insecticide, with the

Table 3. Average yield losses used for the non-neonicotinoid scenario.

		Yield Loss (% per Treated Acre)		**% Planted Acres Treated**	**Yield Loss** (% per Planted Acre)	
Crop	**Nation**	**Low**	**High**		**Low**	**High**
Corn	USA	4.0%	4.4%	88.9%	3.6%	3.9%
Cotton	USA	0.7%[a]		65.3%	0.5%[a]	
Potato	USA	12.6%[a]		34.7%	4.4%[a]	
Sorghum	USA	5.9%[a]		43.1%	2.5%[a]	
Soybean	USA	1.0%	1.3%	39.8%	0.4%	0.5%
Tomato[b]	USA	4.1%	8.2%	62.2%	2.6%	5.1%
Wheat	USA	12.1%	12.9%	20.0%	2.4%	2.6%
Canola	Canada	9.7%	18.9%	87.2%	8.5%	16.5%
Corn	Canada	4.4%	9.8%	75.1%	3.3%	7.4%
Soybean	Canada	1.3%	3.3%	66.2%	0.8%	2.2%

[a] Only one yield loss scenario developed.
[b] The same value used for both fresh and processed tomato.

proportion of acres targeting soil dwelling pests used as the weights. For U.S. soybean, 31.5 percent of neonicotinoid product acres are targeted at soil dwelling insects and 68.5 percent at above-ground pests, based on the GfK Kynetec data for the U.S. (Mitchell 2014b). Thus, the yield loss is 31.5 percent of the yield benefit relative to no insecticide and 69.5 percent of the yield benefit relative to non-neonicotinoid alternative insecticides, since for soil-dwelling pests the growers have no practical alternative insecticides but do have alternatives for above-ground pests. As a result, for the low yield loss scenario, the yield loss is 31.5% x 2.8% + 0.2% x 38.5% = 1.0% as reported in Table 3, where 2.8 percent is the yield benefit relative to no insecticide for the U.S. observations in Table 2 of Mitchell (2014c) and 0.2 percent is the yield benefit for the U.S. observations relative to a non-neonicotinoid insecticide in Table 3 of Mitchell (2014c). The high yield loss scenario uses the same weights, but the yield benefits for all observations in Tables 2 and 3 for soybean, which gives the 1.3 percent yield loss as reported in Table 3. For Canadian soybean, the same weights are used, but the low yield loss scenario uses the yield benefits for all observations in Tables 2 and 3 for soybean, while the high yield loss scenario uses the yield benefits for the Canadian observations in Tables 2 and 3 for soybean. Finally, for U.S. wheat, the weights are 73.1 percent and 26.9 percent for the percentage of treated acres targeted at soil-dwelling and above-ground pests, respectively, and the low yield loss scenario uses the yield benefits for the U.S. observations in Tables 2 and 3 for wheat and the high yield loss scenario uses the yield benefits for all observations in Tables 2 and 3 for wheat.

For tomato, Mitchell (2014c) did not separately analyze the small plot field plot data for fresh and processed tomato, and so the same yield loss (i.e., 23.2 percent) is used for both fresh and processed tomato. Furthermore, Mitchell (2014c) did not analyze data for the yield benefits relative to alternative non-neonicotinoid insecticides, only relative to no insecticide, and so the yield benefit relative to no insecticide is used to estimate the yield benefit relative to alternative non-neonicotinoid insecticides. Specifically, the ratio of the yield benefit for all observations in Table 3 of Mitchell (2014c) to the yield benefit for all observations in Table 2 of Mitchell (2014c) was calculated for each crop, and then the simple average of this ratio calculated across crops, giving 0.177. The implication is that, on average for these crops, the yield benefit for a neonicotinoid insecticide relative to a non-neonicotinoid alternative insecticide is 17.7 percent of the yield benefit for a neonicotinoid insecticide relative to no insecticide. As a result, the estimated per acre yield loss for tomatoes treated with a neonicotinoid insecticide relative to a non-neonicotinoid alternative is 23.2 % x 17.7 % = 4.1% as reported in Table 3. Finally, based on the comments of tomato growers from the listening session in Florida of the substantial yield losses without neonicotinoid insecticides (p. 16, Shaw and Genskow 2014), this yield loss is doubled for a high yield loss scenario.

These descriptions explain how the yield losses as the percentage loss per acre treated with neonicotinoid insecticides were derived for each crop in Table 3. Next, these losses for each crop and scenario were converted to average yield losses per planted acre for the crop as a whole, since the shift needed for the analysis is the decrease in aggregate supply. Multiplying the average yield loss per acre treated with neonicotinoid insecticides by the percentage of planted acres treated with neonicotinoid insecticides for each crop gives the implied average yield losses per planted acre, as reported in the right two columns of Table 3. It is these yield losses that are used to parameterize AGSIM for U.S. corn, soybean, wheat, cotton and sorghum loses under the non-neonicotinoid scenario and for the loss (L) for the partial equilibrium analysis for the other crops.

For clarity, Table 4 pulls all the cost and yield loss assumptions used for the economic analysis for each crop and nation into a single table and indicates the method used for the economic analysis. Based on the values in Table 4, the following eight combinations of cost and yield losses are possible for the non-neonicotinoid scenario: 1) low cost change, no yield loss; 2) high cost change, no yield loss; 3) no cost change, low yield loss; 4) low cost change, low yield loss; 5) high cost change, low yield loss; 6) no cost change, high yield loss; 7) low cost change, high yield loss; and 8) high cost change, high yield loss.

Table 4. Final average cost impacts ($ per planted acre) and average yield losses (percent per planted acre) and economic analysis method used for each crop.

<table>
<tr><th></th><th></th><th colspan="2">Cost Impact
($ per planted acre)</th><th colspan="2">Yield Loss
(% per planted acre)</th><th></th></tr>
<tr><th>Crop</th><th>Nation</th><th>Low</th><th>High</th><th>Low</th><th>High</th><th>Analysis Method</th></tr>
<tr><td>Corn</td><td>USA</td><td colspan="2">7.40</td><td>3.6 %</td><td>3.9%</td><td>AGSIM</td></tr>
<tr><td>Cotton</td><td>USA</td><td colspan="2">1.44</td><td colspan="2">0.5%</td><td>AGSIM</td></tr>
<tr><td>Potato</td><td>USA</td><td>11.38</td><td>22.76</td><td colspan="2">4.4%</td><td>Partial Equilibrium</td></tr>
<tr><td>Sorghum</td><td>USA</td><td colspan="2">4.48</td><td colspan="2">2.5%</td><td>AGSIM</td></tr>
<tr><td>Soybean</td><td>USA</td><td colspan="2">1.31</td><td>0.4%</td><td>0.5%</td><td>AGSIM</td></tr>
<tr><td>Tomato: Fresh</td><td>USA</td><td>31.22</td><td>62.45</td><td>2.6%</td><td>5.1%</td><td>Partial Equilibrium</td></tr>
<tr><td>Tomato: Processed</td><td>USA</td><td>2.14</td><td>4.28</td><td>2.6%</td><td>5.1%</td><td>Partial Equilibrium</td></tr>
<tr><td>Wheat</td><td>USA</td><td colspan="2">0.49</td><td>2.4%</td><td>2.6%</td><td>AGSIM</td></tr>
<tr><td>Canola</td><td>Canada</td><td colspan="2">2.88[a]</td><td>8.5%</td><td>16.5%</td><td>Partial Equilibrium</td></tr>
<tr><td>Corn</td><td>Canada</td><td colspan="2">6.25[a]</td><td>3.3%</td><td>7.4%</td><td>Partial Equilibrium</td></tr>
<tr><td>Soybean</td><td>Canada</td><td colspan="2">2.18[a]</td><td>0.8%</td><td>2.2%</td><td>Partial Equilibrium</td></tr>
</table>

[a] Expressed as $ U.S. per acre. Assumed conversion is 0.92 $U.S. per $ Canadian.

Table 5. Baseline prices and price changes for each cost and yield loss assumption used for the non-neonicotinoid scenario.

		-- No Yield Loss --		-------- Low Yield Loss ------			-------- High Yield Loss-------		
Crop	Baseline	Low Cost	High Cost	No Cost	Low Cost	High Cost	No Cost	Low Cost	High Cost
Barley ($/bu)	$4.75	-$0.01	-$0.01	$0.01	$0.00	$0.00	$0.01	$0.00	$0.00
Corn ($/bu)	$4.85	$0.02	$0.02	$0.22	$0.24	$0.24	$0.24	$0.26	$0.26
Cotton ($/cwt)	$0.73	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Oats ($/bu)	$2.75	-$0.01	-$0.01	$0.01	$0.00	$0.00	$0.01	$0.00	$0.00
Hay ($/ton)	$155	-$0.09	-$0.09	-$0.80	-$0.73	-$0.73	-$0.86	-$0.78	-$0.78
Peanut ($/lb)	$0.25	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Rice ($/cwt)	$16.90	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Sorghum ($/bu)	$4.55	$0.02	$0.02	$0.16	$0.18	$0.18	$0.17	$0.19	$0.19
Soybean ($/bu)	$11.35	$0.00	$0.00	$0.03	$0.04	$0.04	$0.04	$0.04	$0.04
Wheat ($/bu)	$6.20	-$0.01	-$0.01	$0.21	$0.21	$0.21	$0.23	$0.23	$0.23
Specialty Crops									
Potato ($/cwt)	$9.41	$0.01	$0.03	$0.19	$0.21	$0.22	$0.19	$0.21	$0.22
Tomato									
Fresh ($/cwt)	$31.30	$0.01	$0.01	$0.05	$0.05	$0.06	$0.09	$0.10	$0.10
Processed ($/cwt)	$3.84	$0.001	$0.001	$0.032	$0.033	$0.034	$0.064	$0.064	$0.065
Canadian Crops									
Canola ($/mt)[a]	$462.76	$2.27	$2.27	$29.99	$32.41	$32.41	$62.00	$64.57	$64.57
Corn ($/mt)[a]	$230.16	$0.90	$0.90	$4.03	$4.95	$4.95	$9.25	$10.19	$10.19
Soybean ($/mt)[a]	$487.60	$1.02	$1.02	$2.12	$3.14	$3.14	$5.87	$6.90	$6.90

[a] Expressed as $U.S., to convert, use 0.92 $U.S. per $ Canadian.

4.0 Results and Discussion

Three tables report key result from the AGSIM and partial equilibrium analysis. Table 5 reports price effects, Table 6 reports acreage effects, and Table 7 summarizes impacts on consumer surplus, farm income (producer surplus) and the net effect on social surplus (i.e., the sum of consumer and producer surplus changes).

4.1 Price effects

Table 5 reports baseline prices and the estimated changes from these baseline prices under the different cost and yield loss assumptions used for the non-neonicotinoid scenario. The results show that in terms of equilibrium process, the non-neonicotinoid scenario mostly affects a small set of crops and that the yield impact of the non-neonicotinoid scenario has a much greater effect on equilibrium crop prices than the cost impact of the non-neonicotinoid scenario.

The percentage changes in the equilibrium prices from the baseline are not reported but indicate which crops have the largest relative price changes. For U.S. commodity crops, corn, sorghum and wheat show relatively large percentage changes in equilibrium prices. Projected price changes were not large for U.S. cotton and soybeans because these crops had the smallest yield and cost impacts in Table 4. The other commodity crops had small projected price increases, well less than 1 percent from their baseline because no direct cost and yield impacts were assumed. The resulting projected price changes only occurred due to interactions with the crops that were directly affected. For U.S. specialty crops, potatoes and processing tomatoes (under the high yield loss scenario) show large changes. Projected price changes for tomatoes were smaller even though substantial cost and yield impacts were anticipated (Table 4) because these markets have significant imports (fresh tomatoes) and smaller demand elasticities (Table 1). For the Canadian crops examined, canola shows large percentage changes in equilibrium prices, with large changes for the Canadian equilibrium corn price as well. The large magnitude of the price effects for the Canadian crops occur mostly because of the large magnitude of the anticipated yield effects based on the yield data analyzed (Table 4).

For U.S. corn, projected price increases range from $0.22 to $0.26/bu for the anticipated yield reductions, with the cost impact accounting for only about two cents of this price increase. This price increase represents a 4.5 percent to 5.5 percent increase in the price of corn from the baseline. For U.S. sorghum, the projected price increase ranges from $0.16 to $0.19/bu or about a 3.5 percent to 4.0 percent increase, and from $0.19 to $0.23/bu for U.S. wheat or a 3.4 to 3.7 percent increase. The projected price increase for potatoes is $0.19 to $0.22/cwt or 2.0 percent to 2.3 percent, and $0.03 to $0.07/cwt for processed tomatoes, which is still less than 2 percent. The projected price increase for Canadian canola ranges from about $30 to almost $65 per metric ton or 6.5 percent to 14 percent, from $4 to more than $10 per metric ton for Canadian corn, or about 1.8 percent to 4.4 percent, and about $2 to almost $7 per metric ton for soybean or at most 1.4 percent.[3]

[3] Prices expressed as $U.S.; to convert, use 0.92 $U.S. per $Canadian.

Table 6. Baseline planted acres (1,000s) and acreage changes (1,000s) for each cost and yield loss assumption used for the non-neonicotinoid scenario.

		- No Yield Loss -		------ Low Yield Loss -----			------ High Yield Loss -----		
Crop	**Baseline**	**Low Cost**	**High Cost**	**No Cost**	**Low Cost**	**High Cost**	**No Cost**	**Low Cost**	**High Cost**
Barley	3,000	11	11	-11	-4	-4	-12	-5	-5
Corn	92,000	-266	-266	782	456	456	850	524	524
Cotton	10,600	-1	-1	1	-6	-6	1	-6	-6
Oats	2,500	12	12	-12	-3	-3	-13	-4	-4
Hay	56,700	15	15	146	124	124	156	134	134
Peanuts	1,390	-2	-2	2	-1	-1	2	-1	-1
Rice	3,215	0	0	0	0	0	0	0	0
Sorghum	5,800	-79	-79	-66	-110	-110	-51	-95	-95
Soybeans	76,000	-7	-7	-96	-176	-176	-122	-201	-201
Wheat	50,000	46	46	67	61	61	71	66	66
All AGSIM Crops	301,205	-272	-272	812	343	343	882	412	412
CRP[a]	36,771	0	0	-509	-224	-224	-553	-266	-266
Specialty Crops									
Potato	1,099	-1	-1	43	42	41	43	42	41
Tomato									
Fresh	97	0	0	2	2	2	5	5	5
Processed	279	0	0	6	6	6	12	12	12
Canadian Crops									
Canola	19,927	-10	-10	1,708	1,697	1,697	3,614	3,601	3,601
Corn	3,687	-2	-2	115	113	113	270	267	267
Soybean	4,517	-2	-2	32	30	30	89	87	87

[a] Acres enrolled in the Conservation Reserve Program (CRP).

The price changes in Table 5 are permanent changes in the equilibrium market price that are projected to occur if neonicotinoid insecticides were no longer available. For the U.S. commodity crops modeled by AGSIM, these are the new long-term equilibrium prices projected to occur after the cost and/or yield changes have worked their way through all the inter-related markets (i.e., after farmers have adjusted their crop acreage allocations across to reflect the cost and/or yield changes and the associated changes in the relative profitability of the different crops). For the specialty crops and the Canadian crops, these are medium-term equilibrium prices that are projected to occur if neonicotinoid insecticides were no longer available. These are medium-term because prices and acres have adjusted to reflect the reduced supply and/or higher costs for farmers in the single crop market examined in isolation, but farmers would not yet have reallocated their acres across all their crops to reflect changes in the relative profitability of the different crops.

4.2 Acreage effects

Table 6 reports the changes in the equilibrium acres planted for each crop. For the U.S. commodity crop modeled by AGSIM, these are the long-term shifts in aggregate crop acres after the anticipated cost and/or yield effects have worked their way through the markets, and farmers have adjusted planted acres to reflect changes in relative profitability. For the U.S. specialty crops and the Canadian crops, these are medium term acres shifts – after acres have adjusted to reflect the reduced supply and/or higher costs for farmers in the single crop market examined in isolation, before farmers have reallocated acres across all their crops to reflect changes in relative profitability across crops.

For the U.S. commodity crops modeled by AGSIM, crop acres generally respond to changes in relative profitability – crops more profitable relative to the alternative crops will increase in acres. Higher costs generally decrease crop acres since these costs do not usually increase prices enough to offset the profit loss from the cost increase, and so relative profitability decreases. However, because industry-wide yield reductions increase crop prices, the price increase can offset lower yields per acre so that relative profitability can increase. As a result, crop acres can increase or decrease when aggregate yield losses are imposed for a scenario, depending on the supply and demand relationships and differences in the magnitude of the cost and yield changes across crops. Table 6 reports net planted acreage changes across all of these effects for U.S. commodity crops.

For U.S. specialty crops and the Canadian crops, both the yield and cost effects work to decrease the total amount produced, as Figure 1 shows the total production decreases from Q_0 *to* Q_1. A cost increase implies a net decrease in crop acres, since there is no change on per acre yields. However, when per acre yields decrease, it is unclear whether cropped acres increase or decrease; the final equilibrium depends on whether the percentage decrease in per acre yields, L, is greater or less than the percentage decrease in the total amount produced, $(Q_1 - Q_0)/Q_0$. Given the initial and new aggregate production Q_0 and Q_1 and the initial planted acres A_0 (Table 6), the initial average per acre yield is $Y_0 = Q_0/A_0$. Next, given the per acre percentage decrease in yield for the scenarios with yield loss (Table 4), the new average per acre yield is $Y_1 = Y_0(1 - L)$. Finally, the new planted acres are $A_1 = Q_1/Y_1$ and the change in planted acres is $A_1 - A_0$, which is reported in Table 6 for U.S. specialty crops and the Canadian crops for each scenario.

As Table 6 shows, projected U.S. corn acres increase about 450,000 to 525,000 acres in equilibrium once both the anticipated cost increases and yield losses for the non-neonicotinoid scenario occur. This outcome results because corn's relative profitability in net increases, even with the cost and yield changes, as a result of the price increase. On the other hand, projected sorghum acres decrease in net around 100,000 acres in equilibrium when the anticipated yield and cost changes occur for all crops – the price increasing effect is not enough to make sorghum relatively more profitable compared to corn and other crops. For soybean, even though the yield and cost changes are relatively small compared to those anticipated for the other crops (Table 4), soybean acres in equilibrium are projected to decrease around 175,000 to 200,000 acres. On the other hand, equilibrium wheat acres are projected to increase slightly, around 60,000 to 70,000 acres. Also, hay acres in equilibrium

Table 7. Estimated annual changes in consumer welfare, farm income and net social surplus ($ million per year) for the non-neonicotinoid scenario for commodity crops modeled by AGSIM, and U.S. specialty crops and Canadian commodity crops modeled using partial equilibrium analysis.

	-- No Yield --	----------- Low Yield -----------		----------- High Yield -----------	
AGSIM Commodities	**With Cost**	**No Cost**	**With Cost**	**No Cost**	**With Cost**
Consumer Surplus	-$262	-$3,834	-$4,245	-$4,184	-$4,596
Farm Income	-$647	$894	$351	$968	$426
Net Surplus Change	-$909	-$2,940	-$3,894	-$3,216	-$4,170

	------ No Yield -----		----------- Low Yield -----------			------- High Yield ----------		
U.S. Specialty Crops	**Low Cost**	**High Cost**	**No Cost**	**Low Cost**	**High Cost**	**No Cost**	**Low Cost**	**High Cost**
Consumer Surplus	-$6	-$12	-$93	-$99	-$105	-$107	-$113	-$119
Farm Income	-$10	-$19	-$19	-$28	-$38	-$31	-$40	-$50
Net Surplus Change	-$15	-$31	-$112	-$127	-$143	-$137	-$153	-$169

	------ No Yield -----		----------- Low Yield -----------			------- High Yield ----------		
U.S. Total	**Low Cost**	**High Cost**	**No Cost**	**Low Cost**	**High Cost**	**No Cost**	**Low Cost**	**High Cost**
Consumer Surplus	-$268	-$274	-$3,927	-$4,344	-$4,350	-$4,291	-$4,709	-$4,715
Farm Income	-$657	-$666	$876	$323	$313	$938	$386	$376
Net Surplus Change	-$924	-$940	-$3,052	-$4,021	-$4,037	-$3,353	-$4,323	-$4,339

	-- No Yield --	----------- Low Yield -----------		----------- High Yield -----------	
Canadian Crops	**With Cost**	**No Cost**	**With Cost**	**No Cost**	**With Cost**
Consumer Surplus	-$25	-$258	-$284	-$528	-$568
Farm Income	-$32	$167	$135	$318	$291
Net Surplus Change	-$57	-$91	-$149	-$210	-$276

are projected to increase as well, around 125,000 to 150,000 acres. Projected acreage changes for all other crops are very small. In terms of percentages changes relative to the baseline, all are less than 1 percent except for the decreases for sorghum, which still are projected to be less than 2 percent.

For the non-neonicotinoid scenario, the net effect on U.S. acres planted to these commodity crops is an increase of about 340,000 to 410,000 acres once both the anticipated cost increases and yield losses occur. Most of these new acres brought into production are from acres initially enrolled in CRP, which pays farmers a modest annual fee to remove highly erodible and other environmentally sensitive land from crop production. Once the anticipated yield and cost changes occur, the results in Table 6 show a decrease in CRP acres of 225,000 to 265,000 acres in equilibrium. The remaining acres brought into production, about 120,000 to 145,000 acres, are from land initially not cropped, such as in pasture or otherwise idle.

For U.S. specialty crops, planted acres for potato are projected to increase a little over 40,000 acres after the anticipated yield and cost changes for the non-neonicotinoid scenario occur. For fresh tomatoes, projected acreage increases are smaller, less than 5,000 acres but 6,000 to 12,000 acres for processed tomatoes. In terms of percentage increases from their baseline planted acres, these increases are less than 4 percent for potato acres, not quite 5 percent for fresh tomatoes and 3 percent to 7 percent for processed tomatoes. For the Canadian crops examined, the projected acreage increases for canola are large – 1.7 million to 3.6 million more acres, which represents an 8.5 percent to 18 percent increase from the baseline planted acres. This increase represents a substantial expansion in Canadian canola acres. Even though the projected total market demand at the new equilibrium price is at most 1.4 percent lower, because per acre yield decreased as much as 16.5 percent (Table 4), total planted acres must increase to meet this demand. Projected increases are smaller for corn and soybean – about 115,000 to 270,000 acres for corn and 30,000 to almost 90,000 for soybean. For corn, this increase would be a 3 percent to 7 percent increase, while for soybean, the increase is at most about 2 percent.

For U.S. specialty crops and the Canadian crops examined, the partial equilibrium analysis will project an overall decrease in the total quantity produced (Figure 1), but because of the decrease in per acre yields implied by the yield losses for the non-neonicotinoid scenario, total acreage increases. In a multi-market equilibrium model like AGSIM, these acreage increases would be somewhat mitigated by shifts away from these crops to relatively more profitable crops. Thus it is expected that, in the longer-term, these medium-term acreage increases projected by the partial equilibrium analysis and reported in Table 6 would be reduced to some extent.

4.3 Economic surplus effects

Table 7 summarizes the aggregate economic effects of the non-neonicotinoid scenario in terms of impacts on consumer surplus, farm income (producer surplus) and total social surplus (the sum of consumer surplus and farm income). The estimated losses in social surplus for the non-neonicotinoid scenario are also an estimate of the market-level economic benefits of neonicotinoid insecticides. Overall, the commodity crops modeled by AGSIM involve larger total acreages and total overall crop values than specialty crops, and so effects on social surplus are larger in magnitude for these U.S. commodity crops than for the U.S. specialty crops. For example, based on the initial prices and U.S. production values in Table 1, the total market value of U.S. potato production was $4.0 billion and fresh tomatoes and processed tomatoes were each $1.0 billion. The 2010-2012 average for U.S. corn and soybean was $71.8 billion and $39.9 billion, respectively, which together comprised a little more than half of the market value of all U.S. crop production over this same period ($207.6 billion). Similarly, the total market value of Canadian canola was $8.3 billion, while the values were $2.6 and $2.5 billion, respectively for Canadian corn and soybean, based on the values in Table 1. The implication is that the aggregate economic impacts summarized in Table 7 are dominated in terms of the total value by the economic impacts estimated for the large acreage and large value commodity crops in the U.S. like corn and soybean.

Comparing consumer and producer effects, the largest economic effects of the non-neonicotinoid scenario fall on consumers. In general, consumer effects are much larger than effects on farm income. Furthermore, in many cases, farm income increases for the non-neonicotinoid scenario because the price increasing effects increase overall profit, a common result in analyses of this sort (e.g., Falck-Zepeda et al. 2000; Mitchell 2014d; Moschini et al. 2000; Price et al. 2003).

For the cost only assumption (i.e., assuming no yield loss), all models show that farmers will bear most of the cost increase for the non-neonicotinoid scenario. For example in U.S. commodity crops, of the $909 million loss in surplus, $647 million is borne by farmers and $262 million by consumers (Table 7). This generalization also holds for U.S. specialty crops and Canadian crops as well. In total, the estimated cost increase for the non-neonicotinoid scenario is a net loss of $925 to $940 million annually in the U.S. and $57 million annually in Canada.

With the low yield loss assumption added to the cost increase, net impacts on farm income are positive for U.S. commodity crops and Canadian crops examined, but negative for the U.S. specialty crops analyzed. The implication is that the price increases implied by the reduction in per acre crop yields are enough to increase total profit, since the higher prices are paid for all the remaining crop yields. This is a common result in economic analyses of this sort (e.g., Falck-Zepeda et al. 2000; Mitchell 2014d; Moschini et al. 2000; Price et al. 2003). Consumers bear the cost of the non-neonicotinoid scenario. With the low yield loss assumption and the cost increases, total estimated consumer losses are about $4.2 billion for U.S. commodity crops, about $100 million for U.S. specialty crops and more than $280 million for the Canadian commodity crops examined. With the low yield loss assumption and the cost increases, estimated consumer losses increase, to $4.6 billion for U.S. commodity crops, almost $120 million for U.S. specialty crops and almost $570 million for the Canadian commodity crops examined. These consumer losses for the non-neonicotinoid scenario would be paid by commodity crop consumers, which are mostly the livestock, biofuels and vegetable oil industries, and those buying livestock products (meat, dairy, eggs) and using ethanol, biodiesel and vegetable oils.

Table 7 also reports the net loss in social economic surplus (the net sum of producer and consumer surplus) for the non-neonicotinoid scenario. These values are the estimated aggregate economic losses if neonicotinoid insecticides were no longer available, and so they are also estimates of the economic value of neonicotinoid insecticides to the U.S. and Canadian economies. There are two sources for the economic losses for the non-neonicotinoid scenario examined in this aggregate, market-level analysis – a cost of production increase and a per acre yield decrease. Table 7 shows that the estimated net effect of the non-neonicotinoid scenario in the U.S. is a loss of well over $900 million annually for the cost increase. Combining this cost increase with a yield loss assumption gives an estimated loss of $4.0 billion annually for the low yield loss assumption and $4.3 billion annually for the high loss assumption. For the Canadian crops, the net effect of the cost increase is a loss of $57 million annually, with losses increasing to $150 to $275 million annually once the cost increase and yield losses are combined.[4]

[4] These losses are $62 million and about $160 million to $300 million in Canadian dollars, using a conversion factor of 0.92 U.S. dollars per Canadian dollar.

5.0 Conclusion

These values are estimates of the benefits of neonicotinoid insecticides when measured at the market level for these crops, after prices have re-equilibrated. Specifically, if the only benefit neonicotinoid insecticides generate is lower costs for farmers, then this analysis estimates that this benefit is worth about $925 to $940 million annually in the U.S. for these crops, and not quite $60 million annually in Canada; these estimates depend crucially on the accuracy of the cost values reported in Table 2. If in addition neonicotinoid insecticides also generate yield benefits relative to the available alternatives, then this analysis estimates that, in aggregate, this benefit is worth about $4.0 to $4.3 billion annually in the U.S. for these crops and $150 million to $275 million in Canada; these estimates depend crucially on the accuracy of the yield impacts reported in Table 3.

Note that in the short-term, if neonicotinoids were not available, then the cost and yield effects identified in these analyses would reduce farmer income. Multiplying these yield losses by average per acre yields and total treated acres and market prices would give the total value of these yield losses, and multiplying these per acre cost increases by total treated acres would give the aggregate cost increase. These avoided farmer losses are a short-term estimate of the benefits of neonicotinoid insecticides. The estimated economic benefits reported here are not estimates of this sort. Rather, the estimates here assume prices and total production re-equilibrate via market processes over the medium- or longer-term, and then the estimates not only capture the effects on producer income but also consumer benefits.

The estimated benefits summarized here also do not account for other sources of value for neonicotinoid insecticides. Neonicotinoid insecticides applied as seed treatments have a range of non-monetary benefits to farmers as a result of the convenience and efficacy of pest control, reduced risk of losses, and human safety that are not included in this analysis (Hurley and Mitchell 2014; Shaw and Genskow 2014). Also, the value of the land allocation effects of neonicotinoid insecticides is not included. This analysis projects a net increase of 340,000 to 410,000 new acres converted from non-crop uses, such as planted to grasses and trees for enrollment in the CRP, or pasture. Such land likely generates more benefits for wildlife and has lower soil erosion rates than if used for crops (USDA-FSA 2008; The Wildlife Society 2007). Finally, other broad social impacts are not included, just dollar value estimates of losses in social surplus without neonicotinoid insecticides. For example, the price increases on food, feed grains and vegetables in Table 5 would contribute to higher food prices globally, as both the U.S. and Canada are major exporters of these commodities. Higher food prices then contribute to increased social unrest, particularly in developing nations (Bellemare 2015). Despite not including such benefits, the economic assessment summarized here finds that the nitroguanidine neonicotinoid insecticides generate substantial benefits for the U.S. and Canadian economies.

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7.0 Appendix

7.1 Graphical presentation of conceptual framework with international trade

This appendix provides a graphical overview of the conceptual model underlying the partial equilibrium analysis when international trade is included. Panels A and B in Figure A1 indicate the market equilibrium price and quantity, and the quantity traded between the domestic and ROW markets, as well as the resulting producer and consumer surplus in the both the domestic and ROW markets, assuming linear supply and demand curves. Panel A depicts the initial domestic and ROW markets, while Panel B depicts the same markets after the domestic supply shifts due to changes in the cost of production and yields for the non-neonicotinoid scenario. The total market for the commodity (domestic plus ROW supply and demand) is not depicted.

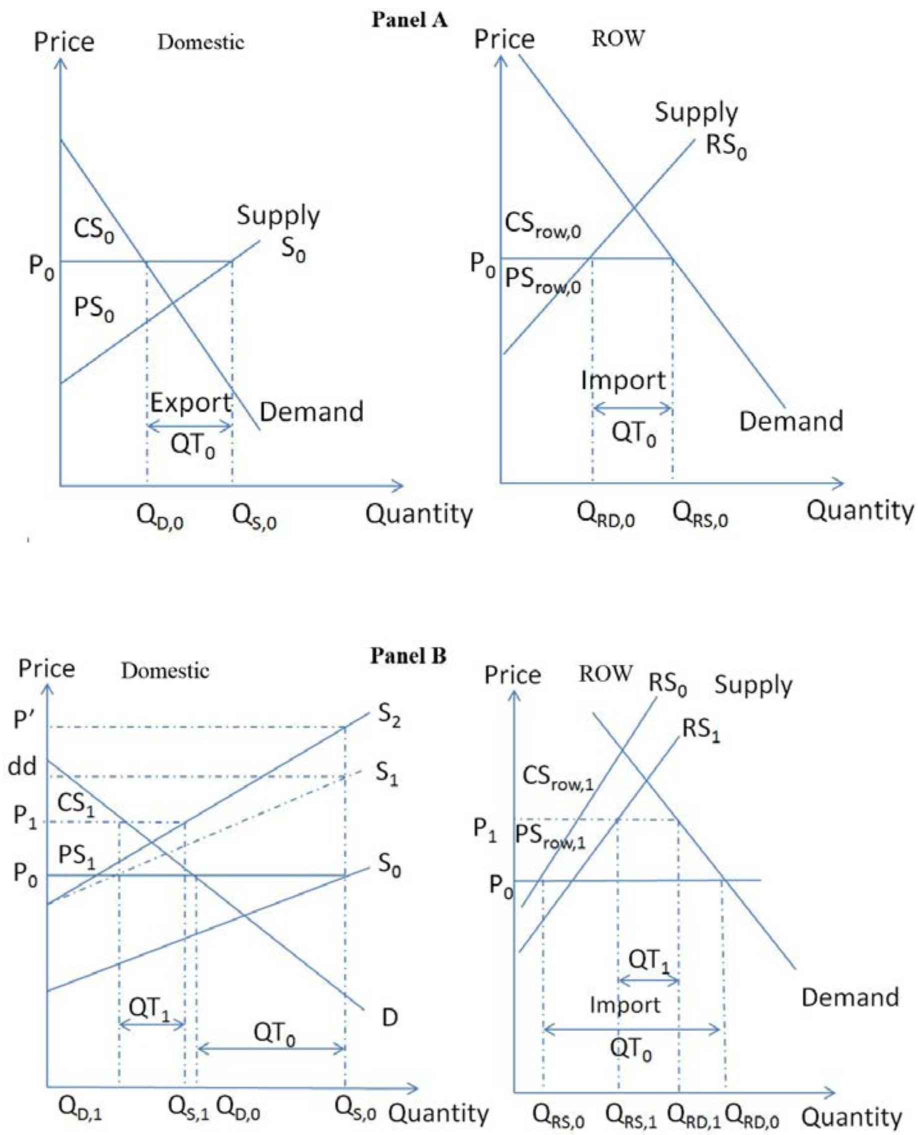
Market equilibrium occurs at the initial price and quantity P_0 and Q_0 at which the total supply equal to the sum of the domestic and rest of world (ROW) supply equals total demand. With international trade, excess demand in one market is satisfied by the excess supply in another marketing being exported. In Panel A, the excess supply produced in the domestic market at the price P_0 is the amount QT_0, which is exported to the ROW to meet the excess demand in the ROW market at the price P_0 that must also equal QT_0 in equilibrium. In a market, the area above the equilibrium price P_0 and below the demand curve out to the equilibrium quantity Q_0 is total consumer surplus, while the area below the equilibrium price P_0 and above the supply curve out to the equilibrium quantity Q_0 is total producer surplus (domestic and ROW). These surpluses are also depicted in Figure A1. In Panel A, PS_0 is domestic producer surplus, CS_0 is domestic consumer surplus, PS_{row} is ROW producer surplus, and CS_{row} is ROW consumer surplus.

Panel B depicts the shifts in the domestic supply curve that result after both the cost and yield changes occur as a result of the non-neonicotinoid scenario. An increase in the cost of production under the non-neonicotinoid scenario implies a contraction or upward shift of the supply curve – farmers would need a higher price to sell any given quantity. With a linear supply curve, this cost change implies a parallel upward shift in the domestic supply curve, from S_0 to S_1 in Panel B. Similarly, a decrease in per acre yield under the non-neonicotinoid scenario also implies a contraction or upward shift of the supply curve – farmers would need a higher price to sell any given quantity. With a linear supply curve, this cost change implies an upward twist of the domestic supply curve, from S_1 to S_2 in Panel B. The final equilibrium occurs at new higher price P_1 and quantity Q_1, with domestic exports of QT_1 that also equal ROW imports. Finally, this new equilibrium generates domestic producer and consumer surplus of PS_1 and CS_1 and ROW producer and consumer surplus of $PS_{row,1}$ and $CS_{row,1}$.

Based on this new equilibrium, the benefit of neonicotinoid insecticides for domestic consumers of this crop is the change in domestic consumer surplus: $CS_1 - CS_0$, since without neonicotinoid insecticides, consumer surplus would decrease to CS_1 from its initial level of CS_0. Similarly, the benefit of neonicotinoid insecticides for domestic producers of this crop is the change in producer surplus: $PS_1 - PS_0$. The net change in domestic social welfare is

the sum of the net change in producer and consumer surplus or $PS_1 - PS_0 + CS_1 - CS_0 = PS_1 + CS_1 - (PS_0 + CS_0)$. Net exports decreases from QT_0 to QT_1. The net change in ROW social welfare is similarly the sum of the net change in ROW producer and consumer surplus or $PS_{row,1} - PS_{row,0} + CS_{row,1} - CS_{row,0} = PS_{row,1} + CS_{row,1} - (PS_{row,0} + CS_{row,0})$. The essence of these measures is the same here as for Figure 1 and the conceptual model presented in the main paper, except that international trade is included. Trade implies consumer and producer surplus change in the ROW, not just in the domestic market, plus net exports also change.

Figure A1. Market equilibrium and producer and consumer surplus in a domestic and world market with trade (Panel A) and how a producer cost increase and yield decrease in the domestic market change supply and producer and consumer surplus in both markets (Panel B).



7.2 Derivation of equations (4) – (7)

Using the same definitions and equations as in the main paper, equation (4) can be derived. First, substitute the definition of

$P_1 = \frac{P_0(a+c+b+d)-ak}{a(1+L)+c+b+d}$ into the definition of the percentage reduction

in price $Z = -\frac{P_1 - P_0}{P_0}$: $Z = -\frac{\frac{P_0(a+c+b+d)-ak}{a(1+L)+c+b+d} - P_0}{P_0}$.

Next, use the definition $k = KP_0$, place the terms in the numerator over the same denominator and simplify the fraction, and then substitute in

$Q_S = A + ak + a(1+L)P$ from equation (2):

$$Z = -\frac{P_0(a+c+b+d) - aKP_0 - [a(1+L)+c+b+d]P_0}{[a(1+L)+c+b+d]P_0},$$

$$Z = \frac{aK + aL}{a(1+L)+c+b+d} \times \frac{P_0 / Q_{S,0}}{P_0 / Q_{S,0}}.$$

Because $Qs = A + aP$, then $a = \frac{\partial Q_S}{\partial P}$, so that the elasticity $\varepsilon = \frac{\partial Q_S}{\partial P}\frac{P_0}{Q_{S,0}}$

can be expressed as $\varepsilon = a\frac{P_0}{Q_{S,0}}$. Substitute this expression for ε into the equation of Z and simplify:

$$Z = \frac{K\varepsilon + L\varepsilon}{\varepsilon(1+L) + (c+d)\frac{P_0}{Q_{RD,0} - Q_{RS,0}}\frac{Q_{RD,0} - Q_{RS,0}}{Q_{S,0}} + b\frac{P_0}{Q_{D,0}}\frac{Q_{D,0}}{Q_{S,0}}}.$$

$$Z = \frac{K\varepsilon + L\varepsilon}{\varepsilon(1+L) + \eta_{RED}\frac{Q_{S,0} - Q_{D,0}}{Q_{s,0}} + \eta_D s}.$$

Finally, simplify further to obtain equation (4):

$$Z = \frac{K\varepsilon + L\varepsilon}{\varepsilon(1+L) + \eta_{RED}(1-s) + \eta_D s}.$$

Next, based on this equation for Z, the change in domestic consumer surplus as defined by equation (5) can be derived. First, based on Figure A1, the change in domestic consumer surplus is:

$$\Delta CS = (P_0 - P_1)Q_{D,1} + 0.5(P_0 - P_1)(Q_{D,0} - Q_{D,1}) \ .$$

Next, simplify by pulling out the common term $(P_0$-$P_1)$, and then note that since $Z = -\frac{P_1 - P_0}{P_0}$, then $P_0 - P_1 = ZP_0$:

$$\Delta CS = (P_0 - P_1)[Q_{D,1} + 0.5(Q_{D,0} - Q_{D,1})] \ ,$$

$$\Delta CS = (P_0 - P_1)Q_{D,0}[1 + 0.5\frac{(Q_{D,1} - Q_{D,0})}{Q_{D,0}}],$$

$$\Delta CS = ZP_0Q_{D,0}(1 + 0.5\frac{P_1 - P_0}{P_0}\frac{P_0}{P_1 - P_0}\frac{Q_{D,1} - Q_{D,0}}{Q_{D,0}}),$$

$$\Delta CS = ZP_0Q_{D,0}(1 + 0.5\frac{P_1 - P_0}{P_0}\frac{P_0}{Q_{D,0}}\frac{Q_{D,1} - Q_{D,0}}{P_1 - P_0}),$$

$$\Delta CS = ZP_0Q_{D,0}[1 + 0.5\frac{P_1 - P_0}{P_0}(-\eta_D)] \ .$$

Finally, use $Z = -\frac{P_1 - P_0}{P_0}$ and rearrange this last expression to obtain (5):

$$\Delta CS = P_0Q_{D,0}Z(1 + 0.5Z\eta_D).$$

Next, the change in domestic producer surplus as defined by equation (6) can be derived. First, based on Figure A1, the change in domestic producer surplus is:

$$\Delta PS = (P_1 - dd)Q_{S,0} + 0.5(P_1 - P^{'})(Q_{S,1} - Q_{S,0}) + 0.5(dd - P^{'})Q_{S,0}.$$

The definition of k implies $k = P_0 - dd = KP_0$. Using $P_0 - dd = KP_0$ and $P_0 - P_1 = ZP_0$, as well as equation (2) and the original supply function $Qs = A + aP$, ΔPS can be derived as:

$$\Delta PS = [(P_0 - d) - (P_0 - P_1)]Q_{s,0} + 0.5[(P_1 - P_0) + (P_0 - P^{'})](Q_{S,1} - Q_{S,0}),$$
$$+ 0.5[(P_0 - P^{'}) - (P_0 - d)]Q_{S,0}$$

$$\Delta PS = (KP_0 - ZP_0)Q_{s,0} + 0.5[-ZP_0 + (P_0 - \frac{1-K}{1+L}P_0)](Q_{S,1} - Q_{S,0}) \\ + 0.5(P_0 - \frac{1-K}{1+L}P_0 - KP_0)Q_{S,0},$$

$$\Delta PS = P_0 Q_{S,0}(K - Z) + 0.5 P_0 Q_{S,0}(-Z + 1 - \frac{1-K}{1+L})\frac{Q_{S,1} - Q_{S,0}}{Q_{S,0}} \\ + 0.5 P_0 Q_{S,0}(1 - K - \frac{1-K}{1+L}),$$

$$\Delta PS = P_0 Q_{S,0}(K - Z) + 0.5 P_0 Q_{S,0}(-Z + 1 - \frac{1-K}{1+L})\varepsilon[-Z + L(1-Z) + K] \\ + 0.5 P_0 Q_{S,0}(1 - K - \frac{1-K}{1+L}).$$

Next, the change in domestic producer surplus as defined by equation (6) can be derived. First, based on Figure A1:

$$\Delta TS = (P_0 - P_1)Q_{T,0} + 0.5(P_0 - P_1)(Q_{T,0} - Q_{T,1}).$$

Use $P_0 - P_2 = ZP_0$ and multiply the final terms by $Q_{T,0} / Q_{T,0} = 1$:

$$\Delta TS = ZP_0 Q_{T,0} + 0.5 ZP_0 Q_{T,0}\frac{Q_{T,0} - Q_{T,1}}{Q_{T,0}},$$

$$\Delta TS = ZP_0 Q_{T,0}(1 + 0.5\frac{Q_{T,0} - Q_{T,1}}{Q_{T,0}}).$$

By definition, $\eta_{RED} = \left| \frac{\partial(Q_{RD,0} - Q_{RS,0})}{\partial P} \frac{P_0}{Q_{RD,0} - Q_{RS,0}} \right|$, but $Q_{RD,0} - Q_{RS,0} = Q_{T,0}$, so that $\eta_{RED} = \left| \frac{\partial Q_{T,0}}{\partial P} \frac{P_0}{Q_{T,0}} \right|$. Next use $\left| \frac{\partial(Q_{RD,0} - Q_{RS,0})}{\partial P} \right| = \left| \frac{Q_{T,0} - Q_{T,1}}{P_0 - P_1} \right|$, and rewrite $\eta_{RED} = \left| \frac{\partial Q_{T,0}}{\partial P} \frac{P_0}{Q_{T,0}} \right|$ as

$$\eta_{RED} = \left| \frac{Q_{T,0} - Q_{T,1}}{P_0 - P_1} \frac{P_0}{Q_{T,0}} \right|.$$

Reorganizing this expression gives $\eta_{RED} = \left| \frac{Q_{T,0} - Q_{T,1}}{Q_{T,0}} \frac{P_0}{P_0 - P_1} \right|$, so that $\left| \frac{Q_{T,0} - Q_{T,1}}{Q_{T,0}} \right| = \left| \frac{P_0 - P_1}{P_0} \right| \eta_{RED}$. Substitute this expression and $Z = -\frac{P_1 - P_0}{P_0} = \left| \frac{P_0 - P_1}{P_0} \right|$ into $\Delta TS = ZP_0 Q_{T,0}(1 + 0.5 \frac{Q_{T,0} - Q_{T,1}}{Q_{T,0}})$

and simplifying gives equation (7):

$$\Delta TS = ZP_0 Q_{T,0}(1 + 0.5 \frac{Q_{T,0} - Q_{T,1}}{Q_{T,0}}) ,$$

$$\Delta TS = ZP_0 Q_{T,0}(1 + 0.5 \left| \frac{P_0 - P_1}{P_0} \right| \eta_{RED}) ,$$

$$\Delta TS = ZP_0 Q_{T,0}(1 + 0.5 Z \eta_{RED}) .$$

7.3 Estimation results

Reduced form, double-log supply and demand equations for each crop were estimated in SAS, version 9.4 (SAS Institute, Cary, NC) using ordinary least squares. More specifically, as expressed in equation (1), the general model for supply, demand, and net trade are

$$\begin{aligned} q_S &= a_0 + a_1 x_1 + a_2 x_2 + \ldots + ap + e_S \\ q_D &= b_0 + b_1 z_1 + b_2 z_2 + \ldots + bp + e_D \\ q_T &= c_0 + c_1 w_1 + c_2 w_2 + \ldots + cp + e_T \end{aligned} \quad . \qquad \text{(A.1)}$$

Note that the for double log model, $q_S = \ln(Q_S)$, $x_i = \ln(X_i)$, $q_D = \ln(Q_D)$, $z_i = \ln(Z_i)$, $q_T = \ln(Q_T)$, $w_i = \ln(W_i)$, and $p = \ln(P)$. The third equation for Q_T is the quantity traded (net imports or net exports), which uses a vector of variables W as explanatory variables. The benefit of the double-log model is that the estimated coefficients for each regression variable are the elasticities for the original (untransformed) variables. Table A1 summarizes estimation results for each crop. The regression variables for the supply and demand variables are listed in the table, as well as the estimated coefficients/elasticities, and their estimation statistics.

For the supply function for U.S. specialty crops, explanatory variables included in equation (A.1) were expected crop price, production time trend, fertilizer price, and the previous year's planted acreage (i.e., lagged acreage). Growers base future crop production plans on the expected new crop price. Here, the previous year's crop price (i.e., the lagged price) is used as a proxy for the expected crop price. The trend variable captures the effects of technology change over time, and the previous year's acreage captures the tendency of producers to continue production. The price of nitrogen fertilizer is included as a proxy to capture the effect of input prices on input use and consequently, on yield and total production of the crop.

The demand equation for U.S. specialty crops includes the crop price and the U.S. consumer income as explanatory variables in equation (A.1). Higher consumer income generally implies greater consumption of (normal) goods such as food, and so the expected income effect is positive. Because processed tomato demand shows a trend, a time trend variable was included for this crop to capture this effect.

The estimated equation for net U.S. exports for processed tomato and potato included price, as well as GDP for the ROW as a proxy for ROW consumer income, so that conceptually the equation is the same as the domestic demand equation. The potato net export equation also included the U.S. ending stock ratio to capture the perishable nature of stored potatoes. The U.S. is a net importer of fresh tomatoes, so the estimated net import equation not only included the price but also the U.S. production to capture the effect of domestic substitutes for imports.

Estimated supply equations for Canadian canola, corn and soybeans were the same as for the U.S. specialty crops. The explanatory variables included the lagged crop price as a proxy for the expected new crop price, the nitrogen fertilizer price to capture input price effects, lagged acres to capture the tendency of producers to continue production, and finally a trend variable for the effects of technology change over time. In the estimated demand equations, besides their own prices and consumer income variables, prices of the other two field crops are also included. In addition, as the demand of these field crops show a trend in Canada, a trend variable is used to capture this effect. Finally, because these crops can be stored, the previous season's ending stock can affect the current year's demand, and so estimation included the ending stock ratio. Canadian canola and soybean are exported, and so the net import demand equation for the ROW included the crop price and ROW GDP as a proxy for ROW consumer income. However, because Canada has historically been a net corn importer, the ROW net export of corn is estimated instead. Because the U.S. has been the primary exporter of corn to Canada, U.S. corn production affects the export of corn to Canada, and so the ROW net export equation for corn included U.S. corn production. Finally, because Canadian production affects Canadian imports, the Canadian fertilizer price was used to capture the effect of input prices on Canadian corn production and hence, import demand.

Table A1 shows the estimates for the supply and demand equations of each crop. All estimated supply and demand elasticities have their own price effects consistent with economic theory (i.e., downward sloping demand and upward sloping supply in each crop's own price). Both fresh and processed tomato supply are not statistically significantly affected by price but by last season's acreage and trend, indicating some technology improvement

and a continuance in their production. In addition, fresh tomato's supply is also statistically significantly affected by nitrogen price (input cost). In contrast, potato's supply is not only statistically significantly affected by last year's acreage and trend, but also by its own price. All own price demand elasticities that are statistically significant at the 10 percent level. Moreover, fresh tomato and potato's demand are also positively affected by consumer income. The adjusted R-square for the supply and demand equations all exceed 0.75, indicating good fits for each crop.

The estimated ROW net export of fresh tomato to the U.S. shows that when the price is higher, the ROW exports a greater supply to the U.S., which is consistent with an upward sloping supply, and the estimated elasticity is statistically significant. However, the adjusted R-square is quite low, indicating that other factors are also important determinant of ROW net exports to the U.S. The ROW net import of processed tomato is negatively affected by price and statistically significantly, consistent with a downward sloping demand, with a high adjusted R-squared, indicating a good model fit. The adjusted R-square for the ROW net import of potato is low, implying that the ROW net import of potato from the U.S. is not significantly affected by price and ROW consumer income but other factors not included in this regression.

For the Canadian crops, supply is not statistically significantly affected by the lagged/expected crop price; rather the Canadian crop supply is mainly explained by a production trend or the previous year's planted acreage. On the demand side, the price only has a statistically significant effect for soybean. However, estimated demand for all three crops show statistically significant effects for both the trend and the ending stock ratios. Overall, the estimated equations for the Canadian crops show high adjusted R-squared values, except for the corn net import equation, indicating good fits for each crop.

Table A1. Estimated regression coefficients and related statistics for the supply and demand equations for U.S. fresh tomatoes, processed tomatoes and potatoes, and Canadian canola, corn and soybean.

Crop	Equation	Variable	Coefficient	Standard Error	p value
U.S. Fresh Tomato	Supply	Intercept	-0.037	2.142	0.986
		Lagged price	0.100	0.090	0.276
		N Price	-0.217	0.057	0.001
		Lagged acres	0.668	0.179	0.001
		Trend	0.012	0.002	<.0001
	R^2	0.85	Adjusted R^2	0.83	
	Demand	Intercept	-5.624	0.478	<.0001
		Price	-0.080	0.045	0.083
		Income	1.398	0.060	<.0001
	R^2	0.99	Adjusted R^2	0.99	
	ROW Net Export	Intercept	3.586	5.029	0.480
		Price	1.513	0.617	0.019
		U.S. Production	-0.233	0.832	0.781
	R^2	0.33	Adjusted R^2	0.30	
U.S. Processed Tomato	Supply	Intercept	4.103	2.663	0.135
		Lagged price	0.263	0.255	0.311
		N Price	-0.155	0.101	0.138
		Lagged acres	0.419	0.217	0.064
		Trend	0.020	0.002	<.0001
	R^2	0.80	Adjusted R^2	0.78	
	Demand	Intercept	14.033	5.917	0.025
		Price	-0.300	0.153	0.059
		Income	-0.320	0.560	0.573
		Trend	0.020	0.011	0.086
	R^2	0.78	Adjusted R^2	0.76	
	ROW Net Import	Intercept	-47.760	5.702	<.0001
		Price	-1.557	0.971	0.124
		ROW GDP	1.969	0.211	<.0001
	R^2	0.83	Adjusted R^2	0.81	

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Table A1. Continued.

Crop	Equation	Variable	Coefficient	Standard Error	p value
U.S. Potato	Supply	Intercept	4.951	1.082	0.000
		Lagged Price	0.286	0.063	0.000
		N Price	-0.086	0.050	0.103
		Lagged Acres	1.162	0.155	<.0001
		Trend	0.018	0.001	<.0001
	R^2	0.93	Adjusted R^2	0.91	
	Demand	Intercept	7.637	0.726	<.0001
		Price	-0.351	0.073	0.000
		Income	0.424	0.076	<.0001
	R^2	0.81	Adjusted R^2	0.79	
	ROW Net Import	Intercept	-22.235	13.285	0.111
		Price	-0.227	0.724	0.757
		ROW GDP	0.323	0.217	0.153
		U.S. ending stock ratio	-3.331	2.103	0.130
	R^2	0.21	Adjusted R^2	0.09	
Canadian Canola	Supply	Intercept	2.658	1.736	0.142
		Lagged Price	0.255	0.270	0.358
		N Price	0.196	0.341	0.573
		Lagged Acres	0.411	0.233	0.094
		Trend	0.025	0.016	0.141
	R^2	0.87	Adjusted R^2	0.84	
	Demand	Intercept	7.293	1.855	0.001
		Price	-0.128	0.454	0.782
		Income	-0.155	0.247	0.538
		Trend	0.055	0.015	0.002
		Ending stock ratio	-0.136	0.074	0.086
		Soybean price	0.174	0.338	0.613
		Corn price	0.163	0.300	0.594
	R^2	0.89	Adjusted R^2	0.86	
	ROW Net Import	Intercept	-28.823	4.103	<.0001
		Price	-0.083	0.259	0.751
		ROW GDP	1.201	0.161	<.0001
	R^2	0.83	Adjusted R^2	0.81	

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Table A1. Continued.

Crop	Equation	Variable	Coefficient	Standard Error	p value
Canadian Corn	Supply	Intercept	9.311	2.257	0.001
		Lagged Price	0.170	0.141	0.243
		N Price	-0.026	0.201	0.898
		Lagged Acres	-0.193	0.319	0.552
		Trend	0.031	0.011	0.014
	R^2	0.82	Adjusted R^2	0.79	
	Demand	Intercept	9.492	1.147	<.0001
		Price	-0.133	0.168	0.440
		Income	0.044	0.189	0.818
		Trend	0.033	0.010	0.005
		Ending stock ratio	-0.248	0.088	0.011
		Canola price	-0.124	0.252	0.627
		Soybean price	-0.027	0.205	0.895
	R^2	0.91	Adjusted R^2	0.88	
	ROW Net Import	Intercept	-38.268	20.050	0.073
		Price	0.677	1.490	0.655
		Fertilizer price	-1.675	1.516	0.285
		U.S. Corn production	5.407	2.303	0.031
	R^2	0.34	Adjusted R^2	0.23	
Canadian Soybean	Supply	Intercept	0.887	2.370	0.713
		Lagged Price	0.269	0.205	0.205
		N Price	0.215	0.259	0.416
		Lagged Acres	0.638	0.340	0.076
		Trend	0.002	0.022	0.939
	R^2	0.86	Adjusted R^2	0.84	
	Demand	Intercept	13.817	0.816	<.0001
		Price	-0.457	0.193	0.030
		Income	-0.811	0.149	<.0001
		Trend	0.068	0.007	<.0001
		Ending stock ratio	-0.133	0.060	0.041
		Corn price	0.327	0.140	0.031
		Canola price	-0.160	0.192	0.416
	R^2	0.89	Adjusted R^2	0.85	
	ROW Net Import	Intercept	-64.232	12.881	0.000
		Price	-0.093	0.646	0.887
		ROW GDP	2.276	0.477	0.000
	R^2	0.93	Adjusted R^2	0.91	