

ABSTRACT

Title of Document: PROTECTIONISM VERSUS RISK IN
SCREENING FOR INVASIVE SPECIES

Chad Damon Lawley,
Doctor of Philosophy, 2009

Directed By: Professors Erik Lichtenberg and Lars Olson
Department of Agricultural and Resource
Economics

The perception that biosecurity import restrictions are used as disguised barriers to trade is widespread. Despite this perception, there has been little empirical analysis distinguishing genuine attempts to protect against introductions of foreign pests and diseases from attempts to distort trade. In this dissertation, I examine the extent to which enforcement of a biosecurity import standard – US agricultural border inspections for non-indigenous species (NIS) – is used as a disguised barrier to trade. I develop a theoretical model of border inspections that incorporates incentives to protect domestic agricultural producers from import competition as well as incentives to protect against NIS damage associated with agricultural imports. The theoretical model is used to specify an econometric model of border inspection that identifies a parameter representing the implied weight the inspection agency places on domestic producer welfare relative to consumer welfare. The structural model further identifies a parameter representing expected NIS damage as implied by the inspection agency's

choice of inspection intensity. I estimate the parameters of the model using a dataset that documents the outcome of US agricultural border inspections.

I find evidence suggesting that the inspection agency places greater weight on domestic producer welfare relative to consumer welfare, independent of expected NIS damage. Estimates of the implicit weight on domestic producer surplus range from 1 to 1.63. These results suggest that inspection protocols are implemented in a trade distorting manner to the benefit of domestic producers and at the expense of domestic consumers. I also find evidence that border inspections are influenced by terms of trade motives. The evidence that inspections are not implemented in a least trade distorting manner is independent of expected NIS damage. A second outcome of the econometric analysis is an estimate of expected NIS damage: I find that the inspection agency behaves as if expected NIS damage ranges from \$0 to more than \$0.25 per dollar of inspected imports.

.

PROTECTIONISM VERSUS RISK IN SCREENING FOR INVASIVE SPECIES

By

Chad Damon Lawley

Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2009

Advisory Committee:

Professor Erik Lichtenberg, Co-Chair
Professor Lars Olson, Co-Chair
Professor Richard Just
Associate Professor Nuno Limao
Assistant Professor Carol McAusland

© Copyright by
Chad Damon Lawley
2009

Acknowledgements

I thank my wife Yvonne. Being graduate students at the same time has its advantages and difficulties. I'm glad we could make it work.

I thank my advisors, Dr. Erik Lichtenberg and Dr. Lars Olson, for their guidance and encouragement throughout the course of this dissertation. I have especially appreciated the willingness of Dr. Lichtenberg, Dr. Olson, and Dr. Doug Parker to collaborate with me on research projects starting from a very early stage of my graduate program.

Thanks to Dr. Carol McAusland for insightful comments and suggestions at every stage of this dissertation, as well as the invitation to collaborate on a survey of invasive species and trade. Thanks to Dr. Richard Just for valuable suggestions at the prospectus stage and for detailed comments and ideas for future work at the final stage of my dissertation. I thank Dr. Nuno Limao for serving as the Dean's Representative on my advisory committee and for providing comments that improved the final dissertation.

I thank the faculty in the Department of Agricultural Economics at the University of Saskatchewan, particularly Dr. Hartley Furtan, for providing me with a solid foundation on which to begin doctoral studies at the University of Maryland.

I thank Joe Cavey, Ethan Kane, and Pete Touhey of the USDA Animal and Plant Health Inspection Service for access to Plant Protection and Quarantine border inspection data.

Support for my graduate work was provided by a grant from the USDA Beltsville Agricultural Research Center. Resources for the Future provided critical financial support in the final year of my graduate studies through the Joseph L. Fisher Doctoral Dissertation Fellowship.

Table of Contents

Acknowledgements.....	ii
Table of Contents.....	iii
List of Tables.....	iv
List of Figures.....	v
1. Introduction and Policy Background.....	1
1.1 Policy Background.....	6
1.1.1 Institutional History.....	6
1.1.2 Inspection Protocols.....	8
1.1.3 US Vegetable Producers and Import Competition.....	12
2. Theoretical Model.....	14
2.1 Prior Literature.....	14
2.2 The Model.....	18
2.3 Analysis.....	23
2.3.1 Optimal Tariff and Inspection Intensity.....	23
2.3.2 Predetermined Tariff.....	41
2.4 Concluding Remarks.....	60
3. Empirical Framework.....	62
3.1 Prior Literature.....	62
3.2 Empirical Model.....	65
3.3 Econometric Specification.....	70
3.3.1 Reduced Form Specification.....	71
3.3.2 Structural Specification.....	75
3.4 Concluding Remarks.....	82
4. Description of the Data.....	83
4.1 Trade Elasticity Estimates.....	83
4.2 Data.....	86
5. Results.....	93
5.1 Reduced Form Results.....	93
5.1.1 Tomato.....	93
5.1.2 Pepper.....	96
5.1.3 Onion.....	97
5.1.4 Bean/Pea.....	99
5.1.5 Broccoli/Cauliflower.....	100
5.2 Structural Model Results.....	103
5.2.1 Nonlinear instrumental variables.....	104
5.2.2 Linear instrumental variables.....	112
5.2.3 Terms of Trade.....	115
5.2.4 Seasonal Heterogeneity.....	119
5.3 Concluding Remarks.....	127
6. Conclusion.....	131
APPENDIX A: Derivation of Comparative Static Results.....	139
APPENDIX B: PPQ 280 Disposition Codes.....	145
Bibliography.....	149

List of Tables

Table 1: Elasticity estimates	86
Table 2: Weekly summary statistics	92
Table 3: Reduced Form Tomato Results	94
Table 4: Reduced Form Pepper Results.....	96
Table 5: Reduced Form Onion Results.....	98
Table 6: Reduced Form Bean/Pea Results.....	99
Table 7: Reduced Form Broccoli/Cauliflower Results.....	101
Table 8: Parameter estimates with nonlinear instruments	106
Table 9: Expected damage with nonlinear instruments, \$/kg imports (δq)	110
Table 10: Parameter estimates with linear instruments	113
Table 11: Expected damage with linear instruments, \$/kg imports (δq)	115
Table 12: Parameter estimates assuming no terms of trade.....	116
Table 13: Inspected import shares by port at state level.....	121
Table 14: Inspected import shares by geographic region of origin and month	122
Table 15: Tests of equality of seasonal parameters $H_0 : \delta q_{\text{Summer}} = \delta q_{\text{Winter}}$	123
Table 16: Parameter estimates allowing for seasonal heterogeneity	125

List of Figures

Figure 1: Optimal inspection intensity.....	31
Figure 2: Optimal inspection intensity when tariff higher than optimal.....	45
Figure 3: Optimal inspection intensity when tariff lower than optimal.....	46

1. Introduction and Policy Background

New introductions of foreign pests and diseases threaten the productivity of agricultural resources, compromise human health, and threaten the viability of natural ecosystems (Vitousek et al. 1997; Mumford 2002). The predominant pathway of new pest and disease introductions is international trade in agricultural commodities (OTA 1993; NRC 2002; Perrings et al. 2005). The use of biosecurity restrictions on agricultural imports – typically enforced by screening potentially contaminated imports at border crossings and ports of entry – has a long history.¹ Recently, the emergence of a number of high profile biosecurity issues has increased scrutiny of import standards and their enforcement (Waage and Mumford 2008). These measures are often contentious issues in international trade. Uncertainty over potential damage due to foreign pest and disease introductions, combined with a lack of transparency in enforcement, provides government agencies with an avenue to manipulate pre-emptive policy for protectionist purposes. Recognizing the potential for misuse of border inspections, international trade agreements prohibit the use of border inspections as arbitrary or unjustified barriers to trade (Smith 2003).

Regulatory capture of government agencies by domestic producer groups is often suspected to result in excessive use of biosecurity trade restrictions (Josling, Roberts, and Orden 2004). Despite the suspicion of disguised protectionism, little systematic empirical analysis exists that distinguishes genuine attempts to protect

¹ Germany was the first to introduce significant pest legislation in 1875 in response to introduction of the Colorado potato beetle. England followed in 1877 with passage of the Destructive Insects Act. In the US, the first quarantine and destruction legislation was introduced in Massachusetts in 1859. The first federal quarantine was implemented in 1879 when US customs collectors imposed a ninety day quarantine on imports of European cattle (Kreith and Golino 2003).

against foreign pests and diseases from attempts to protect domestic producers from import competition. Distinguishing these two motives requires knowledge of expected damages as well as an assessment of risk preferences and regulatory approaches to risk which often vary across nations and regulatory agencies (Sumner and Tangermann 2002; Margolis, Shogren, and Fischer 2005). In addition, heterogeneity in standards and a lack of systematic data make quantification of the restrictiveness of import standards difficult (Beghin 2008; Beghin and Bureau 2001). Empirical analysis is further complicated due to the fact that the actual degree of enforcement is often imperfect and unobserved.

In this dissertation, I examine the extent to which enforcement of a biosecurity import standard – US agricultural border inspections for non-indigenous species (NIS) – is used as a disguised barrier to trade. In Chapter 2, I develop a theoretical model of border inspections that incorporates incentives to protect domestic agricultural producers from import competition as well as incentives to mitigate NIS damage associated with agricultural imports. Reduced form and structural models – guided by the theory presented in Chapter 2 – of US agricultural border inspections for NIS are presented in Chapter 3. The reduced form model examines the relationship between the observed variables in the model; the impact of the standard political economy variable (the inverse import penetration ratio) on inspection intensity is of particular interest. The structural model incorporates terms of trade motives and identifies a parameter representing the implied weight the inspection agency places on domestic producer welfare relative to domestic consumer welfare. The structural model further identifies a parameter representing expected NIS damage

as implied by the inspection agency's choice of inspection intensity. The parameters of the model are estimated using a dataset that documents the outcome of US agricultural border inspections for fiscal years 2005 thru 2007. The data is described in Chapter 4.

Results of the econometric analyses are presented in Chapter 5. In the structural analysis, I find evidence suggesting that the inspection agency places greater weight on domestic producer welfare relative to domestic consumer welfare (and other components of social welfare), independent of expected NIS damage. The estimated weight on domestic producer surplus ranges from 1 to 1.63, implying domestic consumer welfare is valued at between 61 and 100 percent of domestic producer welfare. I also find that terms of trade are an important determinant of border inspections for a number of the commodities in the analysis. Together, these results suggest that inspection protocols are implemented in a trade distorting manner to the benefit of domestic producers and at the expense of domestic consumers. A second outcome of the structural analysis is an estimate of expected NIS damage: I find that the inspection agency behaves as if expected NIS damage ranges from \$0 to more than \$0.25 per dollar of inspected imports depending on commodity and the season of import. Further, the results of the reduced form analysis support the validity of the structural model.

The analysis presented in this dissertation contributes to three distinct literatures. Previous empirical trade research presents evidence that politically influential domestic production sectors are able to secure favorable trade policies (Trefler 1993; Goldberg and Maggi 1999; Gawande and Bandyopadhyay 2000; Lopez

and Matschke 2006). In recent research, Broda, Limao, and Weinstein (2008) relax the small country assumption typically made in this literature and test for the importance of terms of trade motives. They present evidence that both terms of trade and political economy motives are important determinants of US non-tariff barriers. The frameworks motivating these analyses are often based on theoretical models of tariff formation, whereas the empirical analyses assess the determinants of aggregate measures of non-tariff barriers (Goldberg and Maggi 1999; Gawande and Bandyopadhyay 2000). I extend this literature by focusing on a specific non-tariff barrier in a setting where trade agreements constrain the use of tariffs. I also maintain a tight link between the theoretical model and the empirical analysis.

The empirical trade literature has focused on non-tariff barriers implemented with the clear intent of restricting trade. A related literature examines agricultural non-tariff barriers ostensibly implemented to mitigate sanitary and phytosanitary (SPS) threats. This literature evaluates the welfare consequences of relaxing SPS import standards; evidence of an overly restrictive import standard is based on an assessment of the social welfare consequences of removing the standard, net of expected damage in absence of the standard (see Josling, Roberts, and Orden 2004 for a survey). In some cases, the cost of SPS trade restrictions to domestic consumers outweighs potential damage due to the foreign pest or disease. For example, Peterson and Orden (2008) demonstrate that, given reasonable assumptions about the risk of pest infestation, removal of certain US phytosanitary restrictions on avocado imports from Mexico increases US welfare. An implicit assumption in much of this literature

is that standards are perfectly enforced, which may not always be the case.² I relax this assumption and directly examine enforcement of an SPS import standard.

Finally, this dissertation builds on previous theoretical models of trade and NIS (see Costello, Lawley, and McAusland 2009 for a survey of pre-emptive NIS trade policy). McAusland and Costello (2004) examine enforcement of a standard restricting trade in potentially contaminated imports. Assuming border inspections are imperfect and costly, McAusland and Costello (2004) demonstrate that the optimal import tariff is strictly positive in the presence of NIS risk. This result is independent of political economy, economies of scale, and terms of trade motivations.³ In a political economy model of border inspections and fines, Margolis and Shogren (2007) demonstrate that an increase in inspection stringency due to a constraint on the use of tariffs may result in an effective level of protection greater than the level of protection initially provided by an unconstrained tariff.⁴

I build on prior models of border inspection for NIS in a number of ways. First, I include a domestic production sector, assigning a welfare weight to domestic producer surplus that captures the implicit weight the inspection agency places on domestic producer surplus relative to other components of social welfare. Second, in contrast to prior border inspection models, the theory I develop allows the world price to respond to border inspection stringency, provided the importing country is

² For example, despite an import ban on Argentinean beef, weak border controls led to periodic outbreaks of foot and mouth disease (FMD) in Chile (Fischer and Serra 2000).

³ In an extension of the McAusland and Costello (2004) model, Merel and Carter (2008) demonstrate the efficiency gains of a two part tariff which consists of a uniform import tariff and a fine on detected contaminated imports. Ameden, Cash, and Zilberman (2007) examine exporter response to NIS border enforcement in a model with inspection and fines.

⁴ Margolis, Shogren, and Fischer (2005) incorporate political economy motives into a model of tariffs and NIS. They show that the marginal expected damage due to NIS is incorporated into the politically optimal tariff rate.

sufficiently large.⁵ Third, I use a more general specification of detections than has been used in the existing border inspection literature. Fourth, to maintain consistency with the disposition of contaminated agricultural commodities in the US, I assume detected imports are treated rather than destroyed.

1.1 Policy Background

1.1.1 Institutional History

Inspection of US agricultural imports were initiated in 1881 and the first recorded interception occurred in California in 1891 on a shipment of orange trees from Tahiti (Kreith and Golino 2003). Federally, the United States Department of Agriculture (USDA) began inspecting imported agricultural commodities, primarily nursery stock in 1913, under the authority of the 1912 Plant Quarantine Act (GAO 2006). The Animal and Plant Health Inspection Service (APHIS) was established in 1972, assuming responsibility for various plant and animal health services from the USDA. The plant and animal inspection divisions were merged in 1974 with the creation of the Plant Protection and Quarantine (PPQ) division of APHIS. Beginning in the early 1990s, the Agricultural Quarantine Inspection (AQI) program gave APHIS responsibility for inspection of imported agricultural commodities. The 2000 Plant Protection Act consolidated a number of plant protection statutes, including the Plant Quarantine Act.

⁵ Margolis and Shogren (2007) explicitly model a political economy mechanism by incorporating the Grossman and Helpman (1994) model of trade policy and campaign contributions into a model of border inspections. Batabyal and Beladi (2009) incorporate a number of alternative market structures, including the case of a large importing country, into a model of tariffs and NIS.

Prior to formation of Customs and Border Protection (CBP) of the Department of Homeland Security (DHS), US inspection services were performed by three separate federal agencies; APHIS was responsible for preventing the entry of pests and diseases through the AQI activities of PPQ; the US Customs Service was responsible for collecting import duties, enforcing anti-smuggling laws, and preventing entry of narcotics and drugs; and the Immigration and Naturalization Service was responsible for inspecting foreign visitors to prevent illegal entry into the US. The Homeland Security Act of 2002 transferred responsibility for all three inspection services to the newly formed CBP division of the DHS (GAO 2006). Despite previous concerns regarding the adequacy of agricultural inspections as administered by APHIS, environmental and agricultural groups opposed the transfer due to a concern that agricultural inspections would receive lower priority relative to the other border security responsibilities assigned to CBP (Rawson 2002). Agricultural and environmental groups have continued to press members of Congress to return responsibility for agricultural border inspections to APHIS (Campbell 2007).

In March 2003, more than 1,800 agricultural inspection specialists employed by APHIS were transferred to CBP. Subsequently, CBP has hired more than 630 additional agricultural specialists. Despite increased staffing levels, concern remains that CBP has not developed a risk-based staffing model (GAO 2006). Further, as of 2005 there was a perception among USDA and DHS officials that there was a shortage of agricultural inspectors nationwide (GAO 2006). Since the transfer to CBP in March 2003, officials with the DHS have acknowledged that the frequency of agricultural inspections declined overall. Nonetheless, inspections increased at some

ports, and in particular inspections at land border crossings increased by six percent between 2002 and 2004 (GAO 2006).⁶

1.1.2 Inspection Protocols

Although CBP has responsibility for physically inspecting non-propagative agricultural imports, APHIS maintains responsibility for designing inspection protocols and training inspection staff. APHIS has the authority to regulate US fruit and vegetable imports under Quarantine 56 (Title 7 Code of Federal Regulations §319.56) and the Plant Protection Act. Under this authority, all imports of fruits and vegetables arriving at ports of entry and border crossings may be physically inspected. APHIS maintains a list of ‘actionable’ pests currently not established in the US that would cause significant economic harm to domestic agro-ecosystems or natural ecosystems upon establishment.⁷

Commodities imported under pre-clearance or precautionary treatment programs are subject to specific inspection procedures. The National Agricultural Release Program (NARP) (which replaced the Border Cargo Release Program) has been established for a number of low-risk, high-volume commodities imported primarily from Mexico. Commodities entering under pre-clearance programs, precautionary treatment programs, and the NARP are subject to less frequent physical inspection.

⁶ These figures are based on inspection data recorded in the Work Accomplishment Data System (WADS) maintained by APHIS. The accuracy of WADS data has been questioned by APHIS officials in the past since these statistics are often based on estimates of activity rather than real-time information (GAO 1997).

⁷ Between 1984 and 2001, APHIS intercepted approximately 42,000 actionable pests per year (McCullough et al. 2006).

Steps in the inspection process are detailed in the Fruit and Vegetable Import Manual maintained by APHIS.⁸ The inspection process begins with collection and review of documents accompanying individual consignments. At this point inspectors determine whether or not the consignment fits into a special category, such as pre-clearance or precautionary treatment programs, or whether or not the consignment is in-transit to another country. All consignments of fresh fruits and vegetables require an import permit specific to each commodity – commingled unauthorized commodities must be segregated from authorized commodities.

Among those imports selected for a physical inspection, inspection protocols suggests a representative sample of roughly two percent, by volume (NRC 2002; Venette, Moon, and Hutchinson 2002; Work et al. 2005). Inspection involves offloading the commodity, removing items from containers, and physical inspection which may consist of visual examination, dissection, and the “beat technique” (Venette, Moon, and Hutchinson 2002). The exporter is responsible for supplying the labor to move, open, and repackage sampled containers or boxes. Inspectors look for evidence of insects, mites, mollusks, nematodes, noxious weeds, and pathogens. There are special procedures for inspecting certain fruits and vegetables from specific countries of origin, such as apples, citrus, pears, grapes, and stone fruit from South Africa, apples and pears from Australia or New Zealand, and apples and pears from Chile. Avocados from Michoacan, Mexico, clementines from Spain, kiwi from New Zealand, and pears from China all have specific sampling procedures.

⁸ Accessed online June 18, 2009
http://www.aphis.usda.gov/import_export/plants/manuals/ports/downloads/fv.pdf

Inspection protocols also vary by broad groups of commodities, irrespective of the country of origin. Fleshy or pulpy fruits and vegetables are inspected on the surface for pests or indications of pests boring and feeding. These fruits or vegetables may also be dissected to look for insect larvae and other pests – for example, fresh peppers must be examined both internally and externally. Leafy vegetables are inspected for the presence of mollusks, insect larvae, and signs of insect larvae which involves dissecting the leaf. Legumes, such as fresh beans and peas, are examined for holes bored in the pods and seeds, which provide evidence of the presence of larvae and adult insects. Discoloration, surface irregularities, and malformed pods are used as indicators of diseased legumes. Finally, roots crops are examined for signs of insect boring – if bored holes are found the root is dissected to look for the presence of pests. Surface discolorations, blisters, and depressions indicate potential presence of nematodes. Detection of nematodes requires a physical examination of a cross section of the root vegetable.

In the final stage of the inspection process regulatory action is initiated based on the outcome of inspection results. If an actionable pest is not discovered during the course of inspection, the consignment is released. If a pest is discovered, a determination of the actionable status of the pest is made. Inspectors with authority to identify certain pests or pathogens determine actionable status. However, inspectors may lack identification authority for certain pests or pathogens, in which case the consignment is placed on hold and the intercepted specimen or a digital image of the specimen is sent for identification (typically sent to systematics scientists with the USDA's Beltsville Agricultural Research Center located in

Beltsville, Maryland or the Smithsonian Museum of Natural History in Washington D.C.).

If a detected pest is determined to be actionable, the contaminated consignment is subject to regulatory action prior to entry into the US. Contaminated imports may be destroyed, re-exported to an alternative country, or treated according to a treatment approved by APHIS (typically fumigation by methyl bromide or cold treatment). The majority of non-propagative agricultural commodities are treated. In some cases contaminated imports may not be treated and must be re-exported or destroyed. In other cases, treatable commodities may be destroyed or re-exported depending on the relative costs of treating, destroying, and re-exporting. The decision to treat, re-export, or destroy detected contaminated imports therefore depends on the condition of the product, the value of the product, and the availability of an appropriate treatment technology.

Despite clear guidelines for inspection protocols, adherence to these protocols is variable and this has been the case for some time. A 1997 Government Accountability Office (GAO) report suggested that weaknesses in the staffing models used to allocate inspection resources implied that APHIS had little assurance that it was deploying inspection resources efficiently and effectively (GAO 1997). Inefficient allocation of resources leads to variation in the number of samples selected from inspected cargo as well as variation in the method of obtaining a sample. The use of “tailgate” inspections, where samples are selected on the basis of ease of access as opposed to a representative sample, is common (Venette, Moon, and Hutchinson 2002).

1.1.3 US Vegetable Producers and Import Competition

The empirical component of this dissertation focuses on US border inspection of fresh vegetable imports, including tomato, pepper, onion, bean/pea, and broccoli/cauliflower, all of which are primarily imported from Mexico. Import competition from Mexico is a particularly contentious issue within the US fruit and vegetable sector and trade in these commodities, particularly tomatoes, is subject to a number of non-tariff barriers.⁹ Prior to the North American Free Trade Agreement (NAFTA), seasonal tariff rates applied to fruit and vegetable imports were higher during US harvest seasons. Passage of NAFTA was opposed by US fruit and vegetable growers due to concerns that the phase-out of seasonal fruit and vegetable import tariffs would force US producers to compete directly with cheaper Mexican imports (Orden 1996). Opposition was particularly strong among growers in Florida and California; these grower groups pressed for longer transition periods and “snap-back” provisions to protect against import surges (Avery 1998). As a part of the NAFTA Implementation Act, the US International Trade Commission (USITC) was required to monitor imports of fresh tomatoes and peppers for evidence of import surges thru January 2009 (USITC 2007).

US fruit and vegetable imports have increased significantly since passage of NAFTA, growing from \$2.7 billion in 1990 to \$7.9 billion in 2006. Net vegetable

⁹ Bredahl, Schmitz, and Hillman (1987) provide a history of US barriers to fruit and vegetable imports. Marketing orders for fresh fruit and vegetables typically include minimum quality standards which may be used to generate rents for domestic producers at the expense of consumers (Bockstael 1984; Bredahl, Schmitz, and Hillman 1987). Anti-dumping duties have been used to protect US producers of tomatoes from Mexican import competition (Baylis and Perloff 2010).

imports were \$2.25 billion in 2004-06, primarily sourced from NAFTA countries. Tomatoes and peppers are the top two fresh vegetable imports. In addition to overall import growth, the import share of domestic consumption has increased for a number of vegetable commodities. Overall, the share of imports in total domestic consumption increased from 9.3 percent in 1983-85 to 16.3 percent in 2003-05. Between 1993-95 and 2003-05, the import share of US domestic pepper, tomato, and green bean consumption increased by 173 percent, 146 percent, and 155 percent respectively. The broccoli/cauliflower import share remains below ten percent, but increased by more than 200 percent between 1993-95 and 2003-05. One exception to the trend of increasing import shares is onions; per capita consumption of onions has increased, but the import share has remained level due to a corresponding increase in domestic production (Huang and Huang 2007).

2. Theoretical Model

In this chapter I present a theoretical model of border inspection for NIS. The theoretical model extends the previous literature to include terms of trade and political economy considerations in addition to detection of invasive pests as motivations influencing the intensity of border inspections. I begin with a survey of the prior theoretical literature evaluating trade and NIS. That survey is followed by presentation and analysis of the model. I initially assume that both the tariff rate and inspection intensity are set jointly to maximize a weighted social welfare function. I then assume that the tariff is predetermined and inspection intensity is the sole policy instrument available to the inspection agency. This chapter concludes with a summary of results.

2.1 Prior Literature

The theoretical literature examining trade barriers implemented to prevent introductions of invasive NIS has considered Pigouvian tariffs, mitigation strategies, and border inspections. Political economy and terms of trade motivations have also been incorporated into these models. Paarlberg and Lee (1998) incorporate terms of trade motivations into a model of optimal Pigouvian tariffs. Wilson and Anton (2005) extend the Paarlberg and Lee (1998) model to include mitigation strategies. McAusland and Costello (2004) present a model of contaminated imports and examine the optimal mix of policies, including import tariffs and border inspections. Margolis, Shogren, and Fischer (2005) incorporate political economy into a model of

Pigouvian tariffs and a working paper by Margolis and Shogren (2007) includes political economy in a model of Pigouvian tariffs, border inspections, and fines. Merel and Carter (2008) extend the McAusland and Costello (2004) model to allow for a two-part tariff that includes a fine on detected contaminated imports.

Paarlberg and Lee (1998) derive the optimal tariff for a large importing country in the presence of foot and mouth disease (FMD) risk. The optimal tariff is comprised of a Pigouvian tariff and the standard optimal tariff due to terms of trade motivations. The Pigouvian tariff equates the marginal cost of an increased domestic price with the marginal benefit of reduced risk of FMD infection. The standard optimal tariff component equals the inverse of the export supply elasticity. Wilson and Anton (2005) extend the Paarlberg and Lee (1998) model to allow for mitigation strategies, such as vaccination and culling, in addition to an ad valorem tariff. In both of these models, the large importing country can apply different trade policy to different trading partners on the basis of FMD risk as well as terms of trade considerations. These models assume that the importer sets its border policy unilaterally and foreign retaliation is not considered. Both papers use simulation analysis to evaluate the welfare impacts of different border policies in the presence of different levels of FMD risk.

McAusland and Costello (2004) examine the trade-off between border inspections (when detected imports are destroyed, inspection is equivalent to an endogenous 'iceberg' trade cost) and tariffs in the prevention of unintentional NIS introductions. In the absence of political economy and terms of trade motives and under the assumptions that detection is proportional to the detection rate and that

shipments containing NIS are destroyed, McAusland and Costello (2004) demonstrate that the optimal import tariff is strictly positive even with the option of border inspection. The optimal policy instruments are tied to a number of characteristics of the imported goods, including foreign cost of production, the infection rate of exported goods, and per-unit damages associated with contaminated exports. The proportion of exported goods contaminated with an invasive NIS is exogenous and known with certainty. Damages are assumed to be a linear function of the number of invasive NIS accepted by Home and these damages are known with certainty.¹⁰ In cases where the infection rate or the foreign cost of production is sufficiently high, it is optimal to forego inspections and simply charge the appropriate tariff rate.

McAusland and Costello (2004) extend their basic model to account for exporter efforts to clean goods prior to shipment, thereby treating the infection rate as an endogenous variable. They also extend the model to a two-period dynamic setting where the pest population admitted in the first period grows according to a concave growth function, essentially introducing a non-linear damage term. Assuming second order conditions are satisfied, inspection intensity is never lower in the dynamic versus the static setting, although it may be optimal to set a lower tariff.

The McAusland and Costello (2004) model establishes optimal tariff and inspection intensity in the presence of NIS risk; both of these policy instruments are

¹⁰ I have worked through an extension that incorporates uncertainty regarding the infection rate. This extension tended to make the model intractable. I have also worked through an extension that allows for non-linear damages (a convex general power function). The comparative static results derived in the original McAusland and Costello (2004) model carry through in this extension. One result changes: in the original model it was optimal to not inspect at an infection rate of zero or a very high infection rate, whereas if damages are convex there is a low level of infection (greater than zero) for which optimal inspection intensity is zero. I also incorporated uncertainty regarding the per-unit damages. As the variance in per-unit damage increases the optimal response is to increase both inspections and tariffs.

set independent of political economy and terms of trade motivations. Margolis, Shogren, and Fischer (2005) adapt the Grossman and Helpman (1994) political economy model of tariff formation to the issue of NIS and trade. Their application of the Grossman-Helpman model incorporates the marginal damage due to NIS into the politically optimal tariff rate. Margolis, Shogren, and Fischer (2005) conclude that it is difficult to separate the contribution of political lobbying versus genuine attempts to mitigate NIS risk on the formation of tariff rates.

Margolis and Shogren (2007) follow up on the Margolis, Shogren, and Fischer (2005) paper with another Grossman-Helpman political economy model; in this case the government chooses among fines, border inspections, and a tariff. Margolis and Shogren (2007) assume throughout that the importer is a small country, therefore ignoring terms of trade considerations. Inspections are used to intercept contaminated imports. Rather than rejecting or destroying detected imports, a fine is imposed on contaminated imports and the goods are admitted. Margolis and Shogren (2007) consider both politically optimal and predetermined tariffs. They find that an increase in inspection intensity due to a reduction in the predetermined tariff rate may result in a level of effective protection greater than the level of protection initially provided by the predetermined tariff.

Finally, Merel and Carter (2008) demonstrate the efficiency gains of a two part tariff consisting of a uniform import tariff and a fine on detected contaminated imports. The Merel and Carter (2008) model maintains the basic assumptions of the McAusland and Costello (2004) model: detected imports are destroyed, the importing country is small, there is no domestic production sector, and damage due to NIS is

known with certainty. They consider the case where exporters are able to clean shipments prior to export – an endogenous infection rate. In this model, the optimum uniform tariff on exports received is set to recover inspection costs. The optimal fine is applied to detected imports and set at a rate that covers the expected damage due to all contaminated imports. Essentially, the fine is set to penalize contaminated units such that exporters have an incentive to engage in pre-export cleaning.

2.2 The Model

I generalize the McAusland and Costello (2004) model in several ways. First, I include a domestic production sector. The model assigns a welfare weight to domestic producer surplus that captures the implicit weight the inspection agency places on domestic producer surplus relative to other components of social welfare. Second, in contrast to the prior border inspection literature, I incorporate terms of trade considerations into the model, implying that the world price responds to border inspection stringency provided the importing country is sufficiently large. Third, I use a more general specification of detections as a function of inspection intensity. Finally, I assume that detected contaminated imports are treated rather than destroyed or re-exported. In the US the majority of contaminated imports discovered during the course of agricultural inspections are treated.

I model the choice of inspection intensity by a government agency with a mandate to inspect imports potentially contaminated with NIS. Inspection effort is chosen to maximize a weighted domestic social welfare function that consists of domestic consumer surplus, domestic producer surplus, the cost of border inspections,

tariff revenue, and expected damages due to admitted NIS. The optimal inspection intensity balances the direct cost and benefit of border inspections with the indirect impact of price changes on different components of the weighted social welfare function.

The importing country imports goods potentially contaminated with damaging NIS. Domestic demand for the good is denoted $D(p)$ where p is the domestic price of the good. The domestic import-competing production sector supplies $y(p) > 0$ to the Home market. Net export supply is denoted $x(p^w) > 0$ where p^w is the world price. Net import demand is the difference between domestic consumption and domestic production $m(p) = D(p) - y(p) > 0$.

NIS damage, which may include damage and control costs associated with reduced agricultural productivity as well as impaired ecosystem functioning, is a function of the number of NIS admitted into the importing country. In the absence of border inspections the expected number of NIS admitted is determined by the volume of exports sent to the importer and the expected rate of infection of those exports, denoted q . Total expected damages are a function of the expected number of pests admitted, $\delta qx(p^w)$, where $\delta > 0$ represents expected damage per admitted pest.¹¹

The probability that a NIS establishes in the importing country is therefore increasing in the expected number of introductions $qx(p^w)$. Expected damage per admitted pest

¹¹ In analyses of livestock import protocols implemented to prevent entry of Foot and Mouth Disease (FMD), Paarlberg and Lee (1998) and Wilson and Anton (2005) incorporate damages into the supply function of the import-competing sector (the livestock sector). In this model damages are separable from the import-competing domestic production sector. This reflects the fact that established NIS may harm a number of agricultural crops as well as natural ecosystems.

captures both the extent of the range of NIS establishment as well as expected damage within that range.

The inspection agency inspects potentially contaminated imports at the port of entry. The likelihood of detecting at least one actionable NIS is a function of the expected infection rate and inspection intensity I , where inspection intensity captures the effort devoted to inspections. Effort may vary by the sampling rate per volume of imports as well as the sampling procedure employed. For example, given equivalent sampling rates, an inspection procedure based on a randomized sample is more intensive than an inspection procedure that samples those units most readily available for inspection (sometimes referred to as “tailgate inspections”). Inspection intensity also varies by the effort expended on physical examination (visual examination, dissection, etc.) once a sample has been selected.

Inspections are imperfect and costly. The detection rate, denoted $h(I, q)$, lies between zero and one and is concave in both the expected infection rate and inspection intensity such that $h_I = \frac{\partial h(I, q)}{\partial I} > 0$, $h_{II} = \frac{\partial^2 h(I, q)}{\partial I^2} \leq 0$, $h_q = \frac{\partial h(I, q)}{\partial q} > 0$, and $h_{qq} = \frac{\partial^2 h(I, q)}{\partial q^2} \leq 0$. The sign of the cross product depends on the functional form of the detection rate and, in general, is ambiguous $h_{Iq} = \frac{\partial^2 h(I, q)}{\partial I \partial q} \leq 0$. The total cost of inspection is denoted by $kIx(p^w)$ where $k \geq 0$ represents the per-unit cost of inspection effort.

A specific tariff τ is collected based on the volume of imports. The tariff includes user fees imposed to recover inspection costs as well as any import duties collected at the border.

If an actionable NIS is discovered in the process of inspection, the exporter has the option of treating, re-exporting, or destroying the contaminated imports. In the US the majority of detected agricultural imports are treated and subsequently admitted for consumption. Assuming the treatment technology perfectly destroys the target pest, the number of damaging NIS admitted into Home is proportional to the difference between total infected goods received at the border and infected goods discovered during the course of inspection, $x(p^w)[q - h(I, q)]$.

Trade costs due to inspections may include direct expenditures on treatment of detected contaminated imports as well as indirect costs due to delay of perishable commodities at the border. The direct cost due to treatment is denoted f and the per-unit direct cost of treating contaminated imports is $fh(I, q)$. Indirect trade costs due to inspections include deterioration in product quality due to delay at the border, damage during the course of inspection, as well as increased financing expenses and penalties for late delivery. The per-unit indirect cost due to border inspections is

written as $b(I)$, where $b_I = \frac{\partial b(I)}{\partial I} > 0$ and $b_{II} = \frac{\partial^2 b(I)}{\partial I^2} \geq 0$.

Weighted Social Welfare

Weighted social welfare consists of domestic consumer surplus $\int_p^\infty D(p)dp$,

domestic producer surplus $\int_0^p y(p)dp$, tariff revenue, the cost of border inspections,

and damage due to admitted NIS. Since the actual infection rate is unobserved prior to inspection, inspections are conducted on the basis of the expected infection rate.

The inspection agency maximizes the following weighted social welfare function.

$$(2.1.1) \quad W(I, \tau) = \int_p^\infty D(p)dp + \lambda \int_0^p y(p)dp + \tau m(p) - kIx(p^w) - \delta x(p^w)[q - h(I, q)]$$

where $\lambda \geq 1$ denotes the exogenous weight the government places on domestic producer surplus relative to other components of social welfare. Material balance and price arbitrage conditions close the model:

$$(2.1.2) \quad x(p^w) = m(p)$$

$$(2.1.3) \quad p = p^w + \tau + b(I) + fh(I, q).$$

The equilibrium price and material balance conditions hold simultaneously and determine the expected response of domestic and world prices to changes in both the tariff rate and inspection intensity:

$$(2.1.4) \quad \frac{dp}{d\tau} = \frac{\omega p}{\eta p^w + \omega p} \geq 0$$

$$(2.1.5) \quad \frac{dp^w}{d\tau} = \frac{-\eta p^w}{\eta p^w + \omega p} \leq 0$$

$$(2.1.6) \quad \frac{dp}{dI} = \frac{(b_I + fh_I)\omega p}{\eta p^w + \omega p} \geq 0$$

$$(2.1.7) \quad \frac{dp^w}{dI} = \frac{-(b_l + fh_l)\eta p^w}{\eta p^w + \omega p} \leq 0$$

where $\omega = \frac{\partial x}{\partial p^w} \frac{p^w}{x} \geq 0$ is the export supply elasticity and $\eta = -\frac{\partial m}{\partial p} \frac{p}{m} \geq 0$ is the import demand elasticity.

The response of domestic and world prices to changes in the tariff rate are as expected. An increase in the tariff increases the domestic price while the world price is decreasing in the tariff (the typical terms of trade result). If Home is a small country the world price is unresponsive to changes in the tariff rate; in this case, the full marginal cost due to the tariff is passed through to domestic consumers, $\frac{dp}{d\tau} = 1$.

Assuming a positive infection rate, an increase in inspection intensity increases the domestic price. With respect to the world price, consider the small and large country cases separately. If Home is a small importing country the full marginal trade cost due to inspections is passed through to the domestic price $\frac{dp}{dI} = b_l + fh_l$. Alternatively, if Home is a sufficiently large importer ($\omega < \infty$) then a portion of the trade cost is passed through to the world price, and the world price decreases as inspection intensity increases.

2.3 Analysis

2.3.1 Optimal Tariff and Inspection Intensity

In this section I examine the characteristics of the optimal tariff rate and inspection intensity chosen to maximize the weighted social welfare function. I begin

by deriving the optimal tariff rate as a function of inspection intensity, followed by derivation of the implicit expression for optimal inspection intensity. I present the relationship between these two policy instruments as well as an analysis of the response of the optimal tariff and inspection intensity to the parameters of the model. This section concludes with a summary of the key results.

Tariff Rate

Incorporating the material balance condition into equation (2.1.1), the weighted social welfare function can be rewritten as follows:

$$(2.2.1) \quad \max_{I, \tau} W(I, \tau) = \int_p^\infty D(p) dp + \lambda \int_0^p y(p) dp + m(p) [\tau - kI - \delta(q - h(I, q))].$$

The optimal tariff is chosen to maximize the weighted social welfare function. The first order necessary condition for choice of the tariff is given by

$$(2.2.2) \quad \frac{dW(I, \tau)}{d\tau} = \frac{dp}{d\tau} \left\{ -m + (\lambda - 1)y + \frac{\partial m}{\partial p} [\tau - kI - \delta(q - h)] \right\} + m = 0.$$

Equation (2.2.2) can be solved for the optimal tariff rate as a function of inspection intensity:

$$(2.2.3) \quad \tau(I) = \frac{p^w}{\omega} + (\lambda - 1) \frac{p}{\eta} \frac{y}{m} + kI + \delta(q - h) \geq 0.$$

This tariff rate is the large country, political economy version of the optimal tariff derived in McAusland and Costello (2004). The optimal tariff can be broken down into terms of trade, political economy, and NIS border inspection components.

First, there is the standard terms of trade (or market power) component equal to the ratio of world price over the export supply elasticity $\frac{p^w}{\omega}$. This term captures the import market power of the importing country and reflects the degree to which the importing country can pass the cost of the tariff through to the world price. As the export supply elasticity increases a smaller portion of the tariff is passed through to the world price and the government prefers to impose a smaller tariff.

The standard political economy component of the tariff is represented by $(\lambda - 1) \frac{p}{\eta} \frac{y}{m}$. The tariff increases as the weight the government places on domestic producer surplus λ increases. This implies that the government will prefer to impose a larger import tariff on those commodities with more politically influential import-competing domestic producers. The tariff is also increasing in the inverse import penetration ratio, such that the government prefers to impose a higher tariff on sectors with a larger domestic production sector relative to imports. Finally, as the import demand elasticity increases the domestic price is less responsive to a change in the tariff. Since the tariff is less effective at transferring surplus from consumers to producers the government prefers to impose a smaller tariff.

The NIS border inspection component of the optimal tariff is set to recover the cost of conducting inspections kI and to internalize marginal expected damage due to admitted NIS $\delta(q - h)$. This is the McAusland and Costello (2004) component of the optimal tariff. Note that the cost of conducting border inspections could also be recovered by a user fee, independent of the tariff rate.

Inspection Intensity

Inspection intensity is chosen to maximize the weighted social welfare function presented in equation (2.2.1). The first order necessary condition for choice of inspection intensity is given by

$$(2.2.4) \frac{dW(I, \tau)}{dI} = -m(k - h_I \delta) + \frac{dp}{dI} \left\{ -m + (\lambda - 1)y + \frac{\partial m}{\partial p} [\tau - kI - \delta(q - h)] \right\} = 0.$$

Substituting equations (2.1.4), (2.1.6), and (2.2.2) into equation (2.2.4) and simplifying yields

$$(2.2.5) \quad \frac{dW}{dI} = (b_I + fh_I) \frac{dW}{d\tau} - m(b_I + k - h_I(\delta - f)) = 0.$$

Assuming the tariff is set optimally the first order necessary condition for optimal choice of inspection intensity simplifies to:

$$(2.2.6) \quad \frac{dW}{dI} = -m(b_I + k - h_I(\delta - f)) = 0.$$

Optimal inspection intensity equates the marginal cost of an additional unit of inspection intensity $b_I + k$, with the marginal net benefit of an additional unit of inspection intensity $h_I(\delta - f)$:

$$(2.2.7) \quad \underbrace{b_I + k}_{\text{Marginal cost}} = \underbrace{h_I(\delta - f)}_{\text{Marginal net benefit}}.$$

Note that $\delta > f$ is a necessary condition for positive inspection intensity $I^* > 0$.

This implies that marginal expected damage must exceed marginal treatment cost for border inspection to be worthwhile.

First, I evaluate the conditions under which it is optimal to inspect imports.

Under the assumptions of the McAusland and Costello (2004) model – detected

contaminated imports are destroyed, the detection rate is proportional the infection rate $h = qr(I)$, and $r_I(0) \rightarrow \infty$ – inspection intensity is positive if marginal NIS damage δ exceeds foreign marginal cost of production (denoted c in McAusland and Costello 2004). This implies that optimal inspection intensity is positive for all infection rates below an upper bound on the infection rate defined by $\bar{q} = 1 - \frac{c}{\delta}$. In this model detected imports are treated. The following proposition demonstrates that there is a lower bound on the infection rate (as opposed to an upper bound) below which it is optimal to not inspect.

PROPOSITION 1.

When inspection intensity and the tariff are set optimally, optimal inspection intensity is positive whenever $q > \underline{q}$ such that $\left. \frac{dW}{dI} \right|_{I=0} = mh_I(0, \underline{q})(\delta - f) - m(b_I(0) + k) = 0$.

Proof. When τ is set optimally, $\left. \frac{dW}{dI} \right|_{I=0} = -mh_I(0, \underline{q})(f - \delta) - m(b_I(0) + k) = 0$ by construction. It follows that $\left. \frac{dW}{dI} \right|_{I=0} > 0$ whenever $q > \underline{q}$ and $\left. \frac{dW}{dI} \right|_{I=0} < 0$ whenever $q < \underline{q}$. Since $I \geq 0$, I^* is positive whenever $q > \underline{q}$ and is zero otherwise.

PROPOSITION 1 presents a general condition defining the range of infection rates over which optimal inspection intensity is positive. The following presents special cases corresponding to alternative functional forms of the detection rate $h(I, q)$. First, as in McAusland and Costello (2004), the detection rate may be proportional to the infection rate such that $h = qr(I)$. Second, as demonstrated in the statistical literature on sampling for rare individuals, the detection rate may be

approximated by an exponential distribution, $h = 1 - e^{-qt}$ (Venette, Moon, and Hutchinson 2002).

COROLLARY 1.

If $h = qr(I)$ and $r_I(0) \rightarrow \infty$ then $\underline{q} = 0$ and $I^* > 0$ over all positive infection rates.

Proof. If $h_I(0, q) = qr_I(0) \rightarrow \infty$, then $\left. \frac{dW}{dI} \right|_{I=0} = -mqr_I(0)(f - \delta) \rightarrow \infty$ for all positive infection rates.

As shown in COROLLARY 1, if detections are proportional to the infection rate and $r_I(0) \rightarrow \infty$ (as in McAusland and Costello 2004), then optimal inspection intensity is positive over all infection rates provided marginal damage exceeds the marginal cost of treating detected contaminated imports. Next, consider the lower bound on the infection rate assuming the detection rate is approximated by an exponential distribution.

COROLLARY 2.

If $h = 1 - e^{-qt}$ then $\underline{q} = \frac{b_I(0) + k}{(\delta - f)}$ and $I^* > 0$ if $q > \underline{q}$.

Proof. If $h_I(0, q) = q$, then $\left. \frac{dW}{dI} \right|_{I=0} = -m[q(f - \delta) + (b_I(0) + k)] > 0$ for $q > \underline{q}$.

As McAusland and Costello (2004) point out for the case where detections are proportional to the infection rate, if $h_I(0, q)$ is finite then there is a lower bound on the infection rate below which it is optimal to not inspect. This is confirmed in

COROLLARY 2 which shows that $\underline{q} = \frac{b_I(0) + k}{(\delta - f)}$ if $h = 1 - e^{-qt}$. Note that \underline{q} increases

as the marginal cost due to inspections $b_I + k$ increases, increases as the cost of treating detected imports f increases, and decreases as marginal damage δ decreases.

The fact that there is no upper bound on the infection rate is due to the assumption that detected imports are treated, rather than destroyed. This also assumes that $q < 1$ – if the inspection agency is certain that imports are infected, there is no need to inspect. Also, as pointed out by McAusland and Costello (2004), if the importer is permitted to treat all imports irrespective of the outcome of inspections and expected NIS damage exceeds the cost of treatment, then it is optimal to treat all imports and forego inspections entirely.

Next, I show that it is never optimal for the inspection agency to exhaust all detection opportunities. McAusland and Costello (2004) obtain the same result – I show that their result holds up under the more general specification considered in this model.

PROPOSITION 2.

It is never optimal to exhaust all detection opportunities unless inspection is costless: $h(I^, q) \leq q$ with equality only if $b_I + k = 0$.*

Proof.

The marginal cost of inspection is non-negative by assumption $b_I + k \geq 0$. If all detection opportunities have been exhausted, then $h_I(I^*, q) = 0$ and

$\frac{dW}{dI} = -m(b_I + k)$ is negative unless $b_I + k = 0$. Therefore it is never optimal to exhaust all detection opportunities unless inspection is costless.

At a sufficiently high level of inspection intensity all detection opportunities are exhausted and the marginal benefit of an additional unit of inspection intensity is

zero. When an optimal tariff is imposed inspections are targeted to address the NIS externality, independent of terms of trade and political economy considerations. If the marginal cost of an additional unit of inspection intensity is always positive, $b_I + k > 0$, then it is never optimal to inspect to the point where the marginal benefit of an additional unit of inspection intensity is zero, i.e. it is never optimal to exhaust all detection opportunities.

Comparative Static Analysis

Figure 1 illustrates the derivation of the optimal level of inspection intensity assuming $q > \underline{q}$. Note that the marginal cost curve is increasing in inspection intensity if $b_{II} > 0$ and the net marginal benefit curve is decreasing in inspection intensity if $h_{II} < 0$. When the tariff is set optimally, inspection intensity is purely a function of the cost due to inspections $b_I + k$ and the net marginal benefit due to inspections $h_I(\delta - f)$.

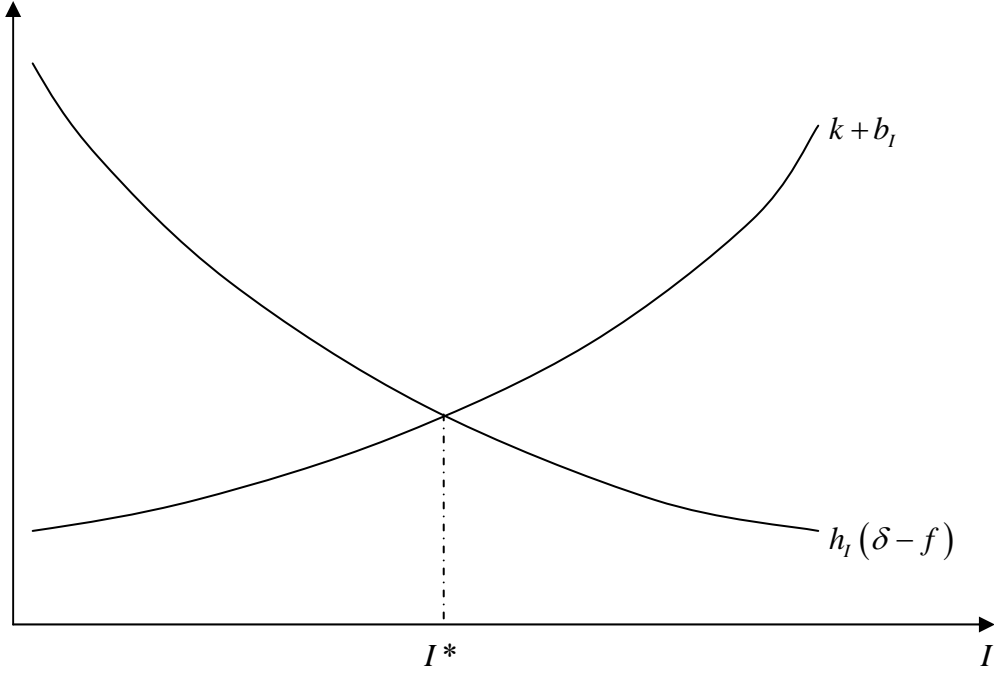


Figure 1: Optimal inspection intensity

The following presents comparative static results with respect to a number of the parameters of the model. I assume that the objective function is locally concave

in the tariff rate $\frac{d^2W}{d\tau^2} < 0$ such that

$$-m \frac{d^2 p}{d\tau^2} \Big/ \frac{dp}{d\tau} + \left(\frac{dp}{d\tau} \right)^2 \left\{ -\frac{\partial m}{\partial p} + (\lambda - 1) \frac{\partial y}{\partial p} + \frac{\partial^2 m}{\partial p^2} [\tau - kI - \delta(q - h)] \right\} + 2 \frac{\partial m}{\partial p} \frac{dp}{d\tau} < 0.$$

Assuming the objective function is locally concave in the tariff rate, combined with assumptions on the primitives of the model – $b_{II} \geq 0$ and $h_{II} \leq 0$ – and the fact that

$\delta > f$ is a necessary condition for positive inspection intensity, ensures that the

second order conditions are satisfied: $\frac{d^2W}{d\tau^2} < 0$, $\frac{d^2W}{dI^2} < 0$, and

$$\frac{d^2W}{dI^2} \frac{d^2W}{d\tau^2} - \left(\frac{d^2W}{dId\tau} \right)^2 > 0. \text{ Detailed expressions for the sufficient conditions and}$$

derivation of the comparative static results are presented in Appendix A.

Although optimal inspection intensity is independent of the tariff rate, equation (2.2.3) shows that the optimal tariff is a function of inspection intensity. The relationship between the optimal tariff and optimal inspection intensity can be derived as follows:

$$(2.2.8) \quad \frac{d^2W}{dId\tau} = (b_I + fh_I) \left[\frac{d^2W}{d\tau^2} - \frac{\partial m}{\partial p} \frac{dp}{d\tau} \frac{1}{m} \frac{dW}{d\tau} \right] = (b_I + fh_I) \frac{d^2W}{d\tau^2} < 0.$$

These two instruments are therefore substitutes, implying that an increase in inspection intensity reduces the optimal tariff rate.

Weight on Domestic Producer Surplus

I begin by examining the optimal policy response to political economy motives. As illustrated in Figure 1 optimal inspection intensity is independent of the weight on domestic producer surplus when the tariff is set optimally. The tariff is a function of the weight on domestic producer surplus and, as expected, the government prefers to impose a larger tariff on imports of commodities produced by politically influential domestic producers. Margolis and Shogren (2007) obtain a similar result. Economic surplus is transferred from consumers to producers through an increase in domestic price. Of the two policy instruments, the tariff is more efficient at achieving the desired transfer. Border inspection increases domestic price but it does so by imposing costs that are not recovered, $b(I) + fh(I, q)$. An import tariff, on the other

hand, increases domestic price in a manner that generates revenue. Therefore, assuming it can set both instruments optimally, the government prefers imposing a tariff to transfer surplus from consumers to producers. PROPOSITION 3 summarizes these results.

PROPOSITION 3.

When the tariff is set optimally

1. *An increase in the weight on domestic producer surplus will have no effect on optimal inspection intensity;*
2. *An increase in the weight on domestic producer surplus will increase the optimal tariff.*

Proof.

1. Differentiating equation (2.2.6) yields $\frac{dI}{d\lambda} = 0$.
2. Differentiating equation (2.2.2) yields $\frac{d\tau}{d\lambda} = -\frac{\frac{dp}{d\tau} y}{\frac{d^2W}{d\tau^2}} > 0$.

Expected NIS Damage

Next, consider the optimal policy responses to expected marginal NIS damage. We can see from Figure 1 that an increase in expected marginal damage δ shifts the net marginal benefit curve up and does not influence the marginal cost curve. This implies that an increase in expected NIS damage increases optimal inspection intensity. The response of the tariff rate is not so straightforward. Since inspection intensity and the tariff rate are substitutes when the tariff is set optimally, it may be optimal to impose a higher or a lower tariff on more damaging imports.

PROPOSITION 4 describes these relationships.

PROPOSITION 4.

When the tariff is set optimally

1. An increase in expected marginal NIS damage will increase optimal inspection intensity;
2. An increase in expected marginal NIS damage will increase (decrease) the

$$\text{optimal tariff rate if } \frac{\frac{\partial m}{\partial p} \frac{dp}{d\tau} (q-h)}{\frac{d^2W}{d\tau^2}} > (<) (b_I + fh_I) \frac{dI}{d\delta}.$$

Proof.

1. Differentiating equation (2.2.6) yields $\frac{dI}{d\delta} = \frac{h_I}{b_{II} + h_{II} (f - \delta)} > 0$.

2. Differentiating equation (2.2.2) and substituting yields

$$\frac{d\tau}{d\delta} = \underbrace{\frac{\frac{\partial m}{\partial p} \frac{dp}{d\tau} (q-h)}{\frac{d^2W}{d\tau^2}}}_{(+)} - \underbrace{(b_I + fh_I) \frac{dI}{d\delta}}_{(-)} \stackrel{>}{<} 0.$$

As in McAusland and Costello (2004), the relationship between the tariff and marginal damage is a function of two opposing forces. First, the Pigouvian component of the tariff is set in order to internalize expected damage due to admitted NIS. The direct response to an increase in expected damage is therefore to increase

the tariff rate, $\frac{\frac{\partial m}{\partial p} \frac{dp}{d\tau} (q-h)}{\frac{d^2W}{d\tau^2}} > 0$. Second, as shown in part 1 of PROPOSITION 4,

when expected damage increases it is optimal to increase inspection intensity. Since the tariff rate and inspection intensity are substitutes an increase in border inspection intensity decreases the optimal tariff, $-(b_I + fh_I) \frac{dI}{d\delta} < 0$. The overall response of the

tariff rate to a change in expected NIS damage depends on the relative magnitude of the Pigouvian versus the substitution effect. If the Pigouvian effect is larger than the

substitution effect, then the tariff increases as expected damage increases. If the substitution effect is larger than the Pigouvian effect, then the tariff will decrease as expected damage increases.

Treatment Cost

The optimal policy response to a change in the cost of treating detected imports is evaluated in PROPOSITION 5. As shown in Figure 1, an increase in marginal treatment cost shifts the net marginal benefit curve down and to the left and leaves the marginal cost curve unchanged. This implies that an increase in treatment cost will reduce optimal inspection intensity. The optimal response of the tariff rate is ambiguous.

PROPOSITION 5.

When the tariff is set optimally

1. *An increase in marginal treatment cost will decrease optimal inspection intensity;*
1. *An increase in marginal treatment cost will increase or decrease the optimal tariff rate.*

Proof.

1. Differentiating equation (2.2.6) yields $\frac{dI}{df} = \frac{-h_I}{b_{II} + h_{II}(f - \delta)} < 0$.

2. Differentiating equation (2.2.2) yields

$$\frac{d\tau}{df} = - \underbrace{\frac{h \left[\frac{d^2W}{d\tau^2} - \frac{\partial m}{\partial p} \frac{dp}{d\tau} \right]}{\frac{d^2W}{d\tau^2}}}_{(+,-)} - \underbrace{(b_I + fh_I)}_{(+)} \frac{dI}{df} \stackrel{<}{\geq} 0.$$

The response of the optimal tariff rate to marginal treatment cost is comprised of two effects. First, there is the direct effect of an increase in the treatment cost on

the tariff. This effect – explored in greater detail in COROLLARY 3 below – trades-off terms of trade and political economy motives for the tariff and is ambiguous. Second, treatment cost has an indirect impact on the tariff via inspection intensity. As treatment cost increases optimal inspection intensity falls. Since the tariff is a substitute for inspection intensity, the optimal tariff increases as inspection intensity falls.

As demonstrated in the following corollary, when the importer is a small country, an increase in treatment cost will unambiguously increase the optimal tariff.

COROLLARY 3.

If the importer is a small country then an increase in the cost of treatment will increase the optimal tariff.

Proof. When the importer is a small country $\frac{dp}{d\tau} = 1$. Assuming $\frac{\partial^2 m}{\partial p^2} \geq 0$ implies

$$\frac{d^2W}{d\tau^2} - \frac{\partial m}{\partial p} \frac{dp}{d\tau} = (\lambda - 1) \frac{\partial y}{\partial p} + \frac{\partial^2 m}{\partial p^2} [\tau - kI - \delta(q - h)] > 0. \text{ This implies that}$$

$$\frac{d\tau}{df} = \underbrace{-\frac{h \left[(\lambda - 1) \frac{\partial y}{\partial p} + \frac{\partial^2 m}{\partial p^2} [\tau - kI - \delta(q - h)] \right]}{\frac{d^2W}{d\tau^2}}}_{(+)} - \underbrace{(b_1 + fh_1) \frac{dI}{df}}_{(+)} > 0.$$

When the importer is a small country an increases in treatment cost increases the optimal tariff rate. This implies that terms of trade effects are responsible for the potentially ambiguous result presented in PROPOSITION 5.. The indirect effect of treatment cost on the tariff rate works as follows. First, when treatment cost increases the domestic price increases. An increase in domestic price reduces imports and increases domestic supply – as a consequence, the ratio of domestic production to

import volume increases. This increases the marginal value of the tariff in terms of shifting surplus from consumers to producers. When the importer is a large country, however, then this price effect is partially absorbed by the world price (reducing the marginal value of an increase in the tariff).

When the importer is a small country, there is no protectionism $\lambda = 1$, and the tariff is set optimally, $\tau = kI + \delta(q - h)$, then $\frac{d\tau}{df} = -(b_i + fh_i) \frac{dI}{df}$. In this case, response of the tariff to an increase in treatment cost is strictly positive and is entirely comprised of the direct substitution of the tariff for inspection intensity.

Infection Rate

The optimal response of inspection intensity to a change in the infection rate is less straightforward than the comparative static results presented above. McAusland and Costello (2004) demonstrate – in the case where detection is proportional to the infection rate and detected imports are destroyed – that the response of inspection intensity to the infection rate is ambiguous: at low infection rates inspection intensity is increasing in the infection rate, whereas at high infection rates inspection intensity is decreasing in the infection rate. This non-monotonicity is due to two opposing factors. First, as the infection rate increases, the marginal productivity of an additional unit of inspection intensity increases ($h_{iq} > 0$ using the notation in this model). Second, as more contaminated imports are detected, and as a consequence rejected, domestic price increases and this increases the marginal value of the last unit rejected.

Under the assumptions of this model the impact of a change in the infection rate on inspection intensity is once again ambiguous. However, in this model the non-monotonicity is due to the ambiguity of the marginal productivity of an additional unit of inspection intensity given an increase in the infection rate ($h_{Iq} \gtrless 0$).

PROPOSITION 6.

When the tariff is set optimally

1. *An increase in the expected infection rate will increase (decrease) optimal inspection intensity if $h_{Iq} > (<) 0$.*
2. *An increase in the expected infection rate will have an ambiguous impact on the optimal tariff rate.*

Proof.

1. Differentiating equation (2.2.6) yields $\frac{dI}{dq} = \frac{-h_{Iq}(\delta - f)}{(b_{II} + h_{II}(f - \delta))} > (<) 0$ if

$$h_{Iq} > (<) 0.$$

2. Differentiating equation (2.2.2) yields

$$\frac{d\tau}{dq} = \frac{\frac{\partial m}{\partial p} \frac{dp}{d\tau} \delta (1 - h_q)}{\underbrace{\frac{d^2W}{d\tau^2}}_{(+,-)}} - \frac{fh_q \left[\frac{d^2W}{d\tau^2} - \frac{\partial m}{\partial p} \frac{dp}{d\tau} \right]}{\underbrace{\frac{d^2W}{d\tau^2}}_{(+,-)}} - \underbrace{(b_I + fh_I)}_{(+,-)} \frac{dI}{dq} \gtrless 0.$$

PROPOSITION 6 demonstrates that optimal inspection intensity may be increasing or decreasing in the rate of infection of imported goods. Under the assumptions used by McAusland and Costello (2004), if a backstop treatment technology is available and the detection rate is proportional to the infection rate, then inspection intensity is non-decreasing in the infection rate. PROPOSITION 6 confirms this. If $h = qr(I)$, then $h_{Iq} = r_I(I) > 0$ and the inspection agency prefers to inspect imports with higher infection rates more intensively.

The McAusland-Costello result does not hold for more general specifications of detection. For example, if the detection rate is approximated by an exponential distribution then $h_{1q} = (1 - qI)(1 - h) \gtrless 0$ and inspection intensity may increase or decrease in response to an increase in the expected infection rate. At low combinations of the infection rate and inspection intensity – specifically, when $qI < 1$ – optimal inspection intensity will increase as the infection rate increases. When the combination of the infection rate and inspection intensity is sufficiently high the marginal detection rate (with respect to the infection rate) decreases with an increase in the infection rate, and optimal inspection intensity will decrease with an increase in the infection rate.

The response of the tariff rate to the expected infection rate is also ambiguous. Three effects determine the relationship between the optimal tariff and the infection rate. First, there is the direct effect of the infection rate corresponding to the

Pigouvian component of the optimal tariff, $\frac{\frac{\partial m}{\partial p} \frac{dp}{d\tau} \delta(1 - h_q)}{\frac{d^2W}{d\tau^2}} \gtrless 0$. The impact of the

first effect is ambiguous. An increase in the infection rate increases expected damage as well as expected detections (this reduces expected damage). The overall impact of the Pigouvian component therefore depends on the relative magnitude of the increase in marginal expected damage versus the increase in the marginal detection rate (with respect to the infection rate).

The second effect is related to the terms of trade and political economy

motives for a tariff, $-\frac{fh_q \left[\frac{d^2W}{d\tau^2} - \frac{\partial m}{\partial p} \frac{dp}{d\tau} \right]}{\frac{d^2W}{d\tau^2}} \underset{<}{\geq} 0$. As shown in COROLLARY 3, if the

importer is a small country, this second effect will have a positive impact on the optimal tariff as the infection rate increases. Also, if the importer is a small country, there is no protectionism ($\lambda = 1$), and the tariff is set optimally, then the second effect goes to zero.

The third effect captures the response of the optimal tariff to a change in inspection intensity, $-(b_l + fh_l) \frac{dI}{dq} \underset{<}{\geq} 0$. This corresponds to the substitution effect described in preceding comparative static results. Since the tariff is a substitute for inspection intensity, this effect adjusts the tariff to offset the change in inspection intensity. In this case, the response of inspection intensity to the infection rate is ambiguous, and the impact of the substitution effect is therefore also ambiguous.

Summary

To summarize, when the tariff and inspection intensity are set optimally, inspection intensity tends to behave as anticipated. Inspection intensity is unresponsive to the weight on domestic producer surplus, consistent with the notion that policy is targeted in order to achieve government objectives in the least distorting manner. It is optimal to increase inspection intensity when the marginal net benefit of inspections (avoided damage minus the cost of treatment) increases. Following similar reasoning, it is optimal to decrease inspection intensity when the cost due to

inspections, including direct price effects and the actual cost of conducting inspections, increases.

The impact of the infection rate on optimal inspection intensity is dependent on the functional form of detections. If detections are proportional to the infection rate then, all else equal, the inspection agency always prefers to inspect imports with a higher expected infection rate more intensively. Alternatively, if detections are best approximated by an exponential distribution, then inspection intensity may be decreasing in the infection rate at a sufficiently high combination of inspection intensity and the infection rate.

As expected, I show that the optimal tariff is increasing in the weight the government places on domestic producer welfare. Although inspection intensity is set independent of the tariff, the optimal tariff is used to substitute for changes in inspection intensity. There are also more direct relationships between the tariff and the parameters of the model and these effects tend to counteract the role of the tariff as a substitute for inspections. As a consequence, a number of the optimal tariff comparative static results are ambiguous.

2.3.2 Predetermined Tariff

In this section I examine the characteristics of optimal border inspection intensity assuming the tariff rate is predetermined. A predetermined tariff may be the outcome of a trade agreement as well as restrictions on the ability of governments to impose import taxes to address NIS threats. Fruit and vegetable imports are a major pathway for NIS introductions into the US and the empirical component of this

dissertation examines border inspection of US fresh vegetable imports primarily sourced from Mexico. The North American Free Trade Agreement (NAFTA) phased out the use of import tariffs on US fruit and vegetable imports from Mexico and Canada. Therefore, the tariff applied to US fresh vegetable imports from North American trading partners is likely too low from a political economy, terms of trade, and NIS perspective.

When the tariff is predetermined the inspection agency chooses inspection intensity to maximize the following weighted social welfare function:

$$(2.3.1) \quad \max_I W(I) = \int_p^\infty D(p)dp + \lambda \int_0^p y(p)dp + m(p) [\tau - kI - \delta(q - h(I, q))].$$

As in the previous section, the first order necessary condition for inspection intensity is written as:

$$(2.3.2) \quad \frac{dW(I)}{dI} = (b_I + fh_I) \frac{dW}{d\tau} - m(b_I + fh_I + k - \delta h_I) = 0.$$

When the tariff is set optimally $\frac{dW}{d\tau} = 0$ and optimal inspection intensity is defined

implicitly by the expression $m(b_I + fh_I + k - \delta h_I) = 0$. If the tariff is not set

optimally, it may be too stringent, in which case $\frac{dW}{d\tau} < 0$, or too lax, in which case

$\frac{dW}{d\tau} > 0$. I examine both cases in the following analysis.

In the previous section, the first order necessary condition for inspection intensity was written such that the marginal cost due to border inspection equaled the marginal net benefit due to border inspection. The first order condition for optimal inspection intensity presented in equation (2.3.2) can be rewritten in a similar manner:

$$(2.3.3) \quad \underbrace{(b_l + k) - b_l \frac{dW}{d\tau} \frac{1}{m}}_{\text{Adjusted marginal cost}} = h_l \underbrace{\left[(\delta - f) + f \frac{dW}{d\tau} \frac{1}{m} \right]}_{\text{Adjusted marginal net benefit}}.$$

I assume that expected marginal damage exceeds the cost of treating detected imports $\delta > f$. Otherwise the inspection agency would allow detected contaminated imports

to enter without treatment. Consider the two cases. If $\frac{dW}{d\tau} < 0$, then the adjusted

marginal cost is strictly positive and $\delta > f$ is a necessary condition for positive

adjusted marginal net benefit. Alternatively, if $\frac{dW}{d\tau} > 0$, then adjusted marginal net

benefit is strictly positive and positive adjusted marginal cost requires that

$$(b_l + k) - b_l \frac{dW}{d\tau} \frac{1}{m} > 0.$$

As in the previous section, I assume the second order sufficient condition is

satisfied, such that $\frac{d^2W}{dI^2} < 0$ (see Appendix A for the full expression). Also, note

that adjusted marginal net benefits are decreasing in inspection intensity if the

following condition holds:

$$(2.3.4) \quad h_{ll} \left[(\delta - f) + f \frac{dW}{d\tau} \frac{1}{m} \right] + \frac{h_{lf}}{m} \left[\frac{d^2W}{d\tau dI} - \frac{dW}{d\tau} \frac{\partial m}{\partial p} \frac{dp}{dI} \frac{1}{m} \right] < 0.$$

Similarly, the adjusted marginal cost curve is upward sloping if the following

condition holds:

$$(2.3.5) \quad b_{ll} \left(m - \frac{dW}{d\tau} \right) - \frac{b_{lf}}{m} \left[\frac{d^2W}{d\tau dI} - \frac{dW}{d\tau} \frac{\partial m}{\partial p} \frac{dp}{dI} \frac{1}{m} \right] > 0.$$

The conditions presented in equations (2.3.4) and (2.3.5), which do not follow from the primitives of the model but are assumed to hold, are sufficient to ensure that the optimal level of inspection intensity is unique.

First, consider the optimal level of inspection intensity when the predetermined tariff is higher than optimal $\frac{dW}{d\tau} < 0$. When the tariff is higher than optimal, the adjusted marginal net benefit of an additional unit of inspection intensity decreases by $h_1 f \frac{dW}{d\tau} \frac{1}{m}$ and the marginal cost due to inspection increases by $b_1 \frac{dW}{d\tau} \frac{1}{m}$. As shown in Figure 2, when the tariff is higher than optimal, the marginal net benefit curve shifts down and to the left, the marginal cost curve shifts up and to the left, and the optimal level of inspection intensity is lower than the first best solution.

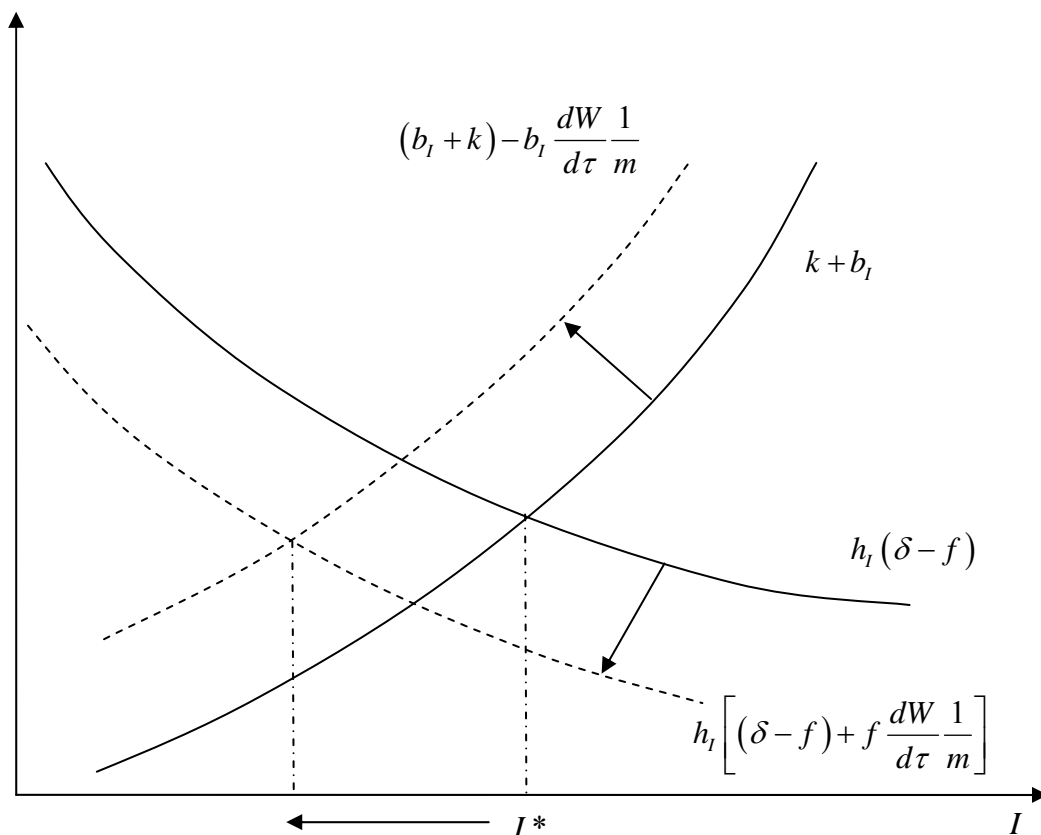


Figure 2: Optimal inspection intensity when tariff higher than optimal

Next, when the predetermined tariff is lower than optimal, $\frac{dW}{d\tau} > 0$, the marginal net benefit of an additional unit of inspection intensity increases by $h_l f \frac{dW}{d\tau} \frac{1}{m}$ and the marginal cost of an additional unit of inspection intensity decreases by $b_l \frac{dW}{d\tau} \frac{1}{m}$. Figure 3 shows that the marginal net benefit curve shifts up and to the right while the marginal cost curve shifts down and to the right. This implies that the optimal level of inspection intensity is greater than the first best solution.

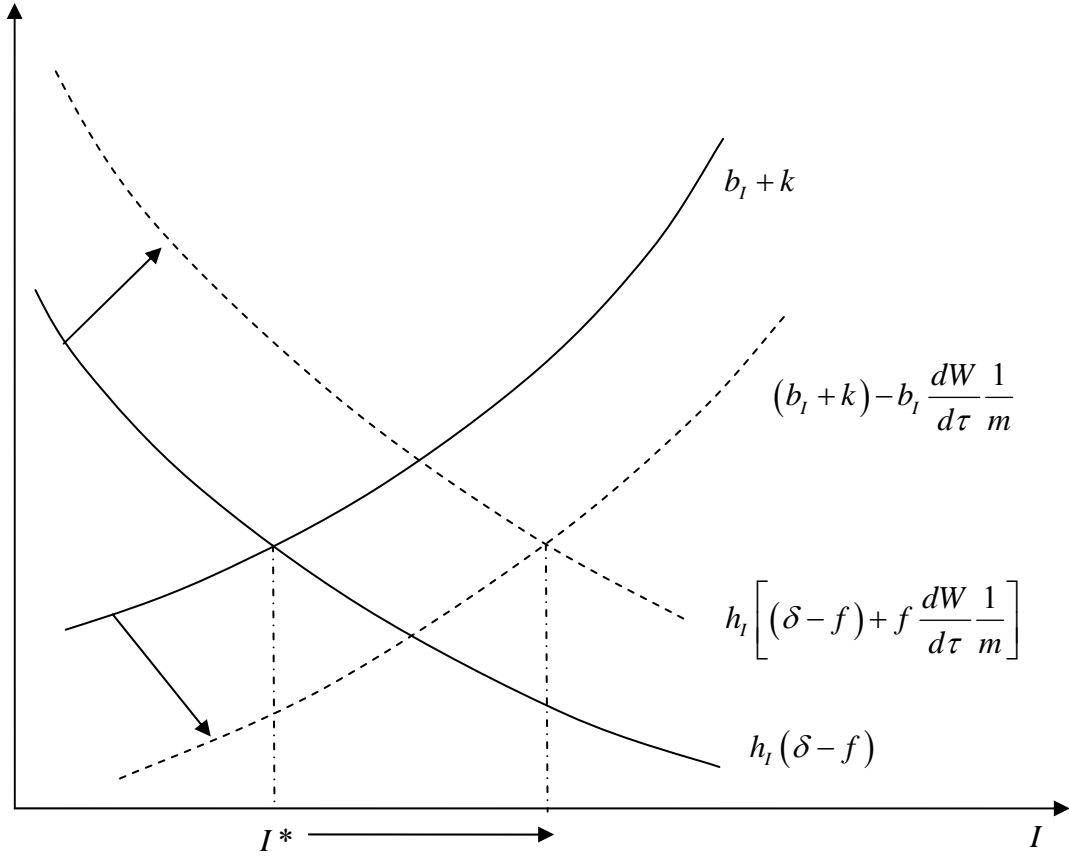


Figure 3: Optimal inspection intensity when tariff lower than optimal

When the tariff is set optimally, the relationships between optimal inspection intensity and the parameters of the model are relatively straightforward. These relationships are more complicated when the tariff is predetermined. Substituting the full expression for $\frac{dW}{d\tau}$ into equation (2.3.3), the adjusted-marginal-cost-adjusted-

marginal-net-benefit equality can be rewritten as:

$$\begin{aligned}
 (2.3.6) \quad & (b_l + k) - b_l \left\{ \left(1 - \frac{dp}{d\tau} \right) + \frac{dp}{d\tau} (\lambda - 1) \frac{y}{m} - \frac{dp}{d\tau} \frac{\eta}{p} [\tau - kI - \delta(q - h)] \right\} \\
 & = h_l \left[(\delta - f) + f \left\{ \left(1 - \frac{dp}{d\tau} \right) + \frac{dp}{d\tau} (\lambda - 1) \frac{y}{m} - \frac{dp}{d\tau} \frac{\eta}{p} [\tau - kI - \delta(q - h)] \right\} \right].
 \end{aligned}$$

When the tariff is set optimally, optimal border inspection intensity is set independent of the weight on domestic producer surplus, the domestic price, and the level of imports. As shown in equation (2.3.6) this independence no longer holds when the tariff is not set optimally. This implies that optimal inspection intensity will depend on the welfare weight the government places on domestic producers. Further, the relationships between optimal inspection intensity and the parameters that influence domestic price (and import volume) – including marginal treatment cost f and the expected infection rate q – are more complicated when the tariff is not set optimally.

The following set of propositions are derived from the implicit expression for optimal inspection intensity presented in equation (2.3.2). As in the previous section, I begin with an evaluation of the conditions under which it is optimal to inspect imports. PROPOSITION 1 presented a general condition for positive optimal inspection intensity when the tariff is set optimally. The following proposition presents a general condition for positive optimal inspection intensity when the tariff is predetermined.

PROPOSITION 7.

When the tariff is predetermined, optimal inspection intensity is positive whenever $q > \underline{q}$ such that

$$\left. \frac{dW}{dI} \right|_{I=0} = h_I(0, \underline{q}) \left[m(\delta - f) + f \left. \frac{dW}{d\tau} \right|_{I=0} \right] - m(b_I(0) + k) + b_I(0) \left. \frac{dW}{d\tau} \right|_{I=0} = 0.$$

Proof. When τ is predetermined,

$$\left. \frac{dW}{dI} \right|_{I=0} = h_I(0, \underline{q}) \left[m(\delta - f) + f \left. \frac{dW}{d\tau} \right|_{I=0} \right] - m(b_I(0) + k) + b_I(0) \left. \frac{dW}{d\tau} \right|_{I=0} = 0 \text{ by}$$

construction. It follows that $\left. \frac{dW}{dI} \right|_{I=0} > 0$ whenever $q > \underline{q}$ and $\left. \frac{dW}{dI} \right|_{I=0} < 0$ whenever $q < \underline{q}$. Since $I \geq 0$, I^* is positive whenever $q > \underline{q}$ and is zero otherwise.

PROPOSITION 7 presents a general condition for positive inspection intensity. As in the previous section, it is useful to consider special cases corresponding to the functional form of the detection rate. The special case where the detection rate is proportional to the infection rate is presented first.

COROLLARY 4.

If $h = qr(I)$, $r_I(0) \rightarrow \infty$, and the tariff is predetermined then $\underline{q} = 0$ and $I^ > 0$ over all positive infection rates.*

Proof. If $h_I(0, q) = q r_I(0) \rightarrow \infty$, then $\left. \frac{dW}{dI} \right|_{I=0} = q r_I(0) \left[m(\delta - f) + f \frac{dW}{d\tau} \right] \rightarrow \infty$ for all positive infection rates.

As in the case where both the tariff rate and inspection intensity are set optimally, COROLLARY 4 shows that inspection intensity is positive over all infection rates when the detection rate is proportional to the infection rate – consistent with the functional form imposed in McAusland and Costello (2004). This also implies that the range of infection rates over which it is optimal to inspect is independent of the level of the predetermined tariff relative to the optimal tariff rate. Next, consider optimal inspection intensity when the detection rate is approximated by an exponential distribution.

COROLLARY 5.

If $h = 1 - e^{-qI}$ and the tariff is predetermined then $\underline{q} = \frac{b_I(0) + k - b_I(0) \frac{dW}{d\tau} \frac{1}{m}}{(\delta - f) + f \frac{dW}{d\tau} \frac{1}{m}}$

and $I^ > 0$ if $q > \underline{q}$.*

Proof. Note that $h_t(0, q) = q$. This implies that

$$\left. \frac{dW}{dI} \right|_{I=0} = m\underline{q}(\delta - f) + f\underline{q} \left. \frac{dW}{d\tau} \right|_{I=0} - m(b_t(0) + k) + b_t(0) \left. \frac{dW}{d\tau} \right|_{I=0} > 0 \text{ for } q > \underline{q}.$$

As shown in COROLLARY 5, if the detection rate is approximated by an exponential distribution, then there is a lower bound infection rate below which it is optimal to not inspect. Once again, this result is consistent with the result obtained when the tariff is set optimally. Inspection of the expression for \underline{q} presented in COROLLARY 5 reveals that the range of infection rates over which inspection intensity is positive varies according to the predetermined tariff rate. If the tariff is less than optimal then \underline{q} is lower than it would be if the tariff was set optimally, and the inspection agency prefers to inspect over a wider range of infection rates.

Alternatively, if the initial tariff is higher than optimal then the inspection agency prefers to inspect over a smaller range of infection rates.

When the tariff and inspection intensity are set optimally and the detection rate is approximated by the exponential distribution, the lower bound on the infection rate decreases in marginal damage, increases in marginal treatment cost, and is independent of the weight on domestic producer surplus. When the tariff is predetermined, the lower bound on the infection rate is decreasing in marginal damage and the weight on domestic producer surplus. Further, the lower bound on the infection rate may be increasing or decreasing in marginal treatment cost. These results are summarized in COROLLARY 6.

COROLLARY 6.

If $h = 1 - e^{-qt}$ and the tariff is predetermined

1. An increase in expected marginal NIS damage will decrease the lower bound infection rate;
2. An increase in the weight on domestic producer surplus will decrease the lower bound infection rate;
3. An increase in marginal treatment cost will increase (decrease) the lower bound infection rate if $\left. \frac{dW}{d\tau} \right|_{I=0} < (>) m$.

Proof. Differentiating the lower bound infection rate $\underline{q} = \frac{b_l(0) + k - b_l(0) \frac{dW}{d\tau} \frac{1}{m}}{(\delta - f) + f \frac{dW}{d\tau} \frac{1}{m}}$

yields:

1. $\frac{d\underline{q}}{d\delta} = - \frac{\underline{q} \left[m - \frac{\partial m}{\partial p} \frac{dp}{d\tau} (b_l(0) + f\underline{q}) \right]}{m(\delta - f) + f \left. \frac{dW}{d\tau} \right|_{I=0}} < 0$.
2. $\frac{d\underline{q}}{d\lambda} = - \frac{\frac{dp}{d\tau} y(b_l(0) + f\underline{q})}{m(\delta - f) + f \left. \frac{dW}{d\tau} \right|_{I=0}} < 0$.
3. $\frac{d\underline{q}}{df} = - \frac{\underline{q} \left(\left. \frac{dW}{d\tau} \right|_{I=0} - m \right)}{m(\delta - f) + f \left. \frac{dW}{d\tau} \right|_{I=0}} \underset{<}{\geq} 0$.

When the tariff is set optimally, an increase in marginal treatment cost reduces the marginal net benefit of an additional unit of inspection intensity and the inspection agency prefers to inspect over a smaller range of infection rates. When the tariff is predetermined, an increase in marginal treatment cost has an additional effect corresponding to the level of the predetermined tariff relative to the optimal tariff. If the tariff is higher than optimal, then the lower bound on the infection rate is increasing in marginal treatment cost. Alternatively, if the predetermined tariff is

lower than optimal, then the lower bound on the infection rate may be increasing or decreasing in marginal treatment cost. The relationship is more likely to be positive if the government prefers to increase the domestic price of imports – due to, for example, an unfulfilled preference (due to a constraint on the use of tariffs) to transfer surplus from domestic consumers to producers.

Finally, consider whether or not the inspection agency finds it optimal to exhaust detection opportunities. Recall that when the tariff is set optimally, it is never optimal to exhaust all detection opportunities unless the marginal cost due to inspection is zero $b_I + k = 0$. In other words, as long as the marginal cost of an additional unit of inspection intensity is costly, the inspection agency will never find it optimal to inspect to the point where the marginal detection rate is zero $h_I = 0$.

PROPOSITION 8.

When the tariff rate is predetermined and

1. *Lower than optimal, then it may be optimal to exhaust all detection opportunities;*
2. *Higher than optimal, then it is never optimal to exhaust all detection opportunities.*

Proof. If all detection opportunities have been exhausted, then $h_I(I^*, q) = 0$ and

$\frac{dW}{dI} = b_I \left(\frac{dW}{d\tau} - m \right) - mk$. If $h_I(I^*, q) = 0$ and $\frac{dW}{dI} < 0$ it is not optimal to exhaust

all inspection opportunities. If $h_I(I^*, q) = 0$ and $\frac{dW}{dI} \geq 0$ it is optimal to exhaust all inspection opportunities.

1. If $\frac{dW}{d\tau} > 0$, then substituting $\left. \frac{dW}{d\tau} \right|_{h=q} = \frac{dp}{d\tau} \left\{ -m + (\lambda - 1)y + \frac{\partial m}{\partial p} [\tau - kI] \right\} + m$

into $\frac{dW}{dI} = b_I \left(\frac{dW}{d\tau} - m \right) - mk$ yields

$\frac{dW}{dI} = b_I \frac{dp}{d\tau} \left(-m + (\lambda - 1)y + \frac{\partial m}{\partial p} [\tau - kI] \right) - mk \gtrless 0$ and it may be optimal to

increase or decrease inspection intensity.

2. If $\frac{dW}{d\tau} < 0$, then $\frac{dW}{dI} = b_I \left(\frac{dW}{d\tau} - m \right) - mk < 0$ and it is optimal to decrease inspection intensity.

In contrast to the case where the tariff rate is set optimally, PROPOSITION 8 demonstrates that it may be optimal to exhaust all detection opportunities if the predetermined tariff is lower than optimal. When the tariff is set optimally, the government has no incentive to use border inspections to transfer surplus to domestic producers, whereas if the tariff is too lax the ‘cost’ of an additional unit of inspection intensity is lower due to political economy motivations. If incentives to transfer surplus to domestic producers are sufficiently high, then the inspection agency will find it optimal to exhaust all detection opportunities.

Comparative Static Analysis

Tariff rate

I begin the comparative static analysis of optimal inspection intensity with the tariff rate. Recall from the previous section that inspection intensity is set independent of the tariff rate and the tariff is a substitute for inspection intensity when both instruments are set optimally. As shown in equation (2.3.6), when the tariff is predetermined the optimal level of inspection intensity is dependent on the tariff. The following proposition examines the response of inspection intensity to a change in the tariff rate.

PROPOSITION 9.

Assuming the objective function is locally concave in the tariff rate, when the tariff rate is predetermined

1. And the initial tariff is higher than optimal, an increase in the tariff rate will decrease optimal border inspection intensity;
2. And the initial tariff rate is lower than optimal, an increase in the initial tariff rate will increase (decrease) optimal inspection intensity if the elasticity of m with respect to τ is greater than (less than) the elasticity of $\frac{dW}{d\tau}$ with respect to τ .

Proof. Differentiating equation (2.3.2) yields

$$\frac{dI}{d\tau} = - \frac{(b_l + fh_l) \left[\frac{\overbrace{d^2W}^{(-)}}{d\tau^2} - \frac{\overbrace{\partial m}^{(+,-)}}{\partial p} \frac{dp}{d\tau} \frac{1}{m} \frac{dW}{d\tau} \right]}{\frac{d^2W}{dI^2}} = - \frac{(b_l + fh_l) \frac{dW}{d\tau} \frac{1}{\tau} \left[\overbrace{\kappa_{\frac{dW}{d\tau},\tau}^{(+,-)}} \overbrace{-\kappa_{m,\tau}^{(+)}} \right]}{\frac{d^2W}{dI^2}} \geq 0, \text{ where}$$

$\kappa_{\frac{dW}{d\tau},\tau} = \frac{d^2W}{d\tau^2} \frac{\tau}{\frac{dW}{d\tau}} \geq 0$ is the elasticity of $\frac{dW}{d\tau}$ with respect to τ and $\kappa_{m,\tau} = \frac{\partial m}{\partial \tau} \frac{\tau}{m}$ is the elasticity of m with respect to τ .

1. If the initial tariff rate is higher than optimal $\frac{dW}{d\tau} < 0$ and $\frac{dI}{d\tau} < 0$.
2. If the initial tariff rate is lower than optimal $\frac{dW}{d\tau} > 0$ and $\frac{dI}{d\tau} > (<) 0$ if

$$\kappa_{m,\tau} > (<) \kappa_{\frac{dW}{d\tau},\tau}.$$

PROPOSITION 9 demonstrates that inspection intensity is used as a substitute for the tariff rate when the initial tariff is higher than optimal. This is consistent with the common notion in the trade policy literature that reductions in tariff rates are offset by increases in the stringency of non-tariff barriers (Josling, Roberts, and Orden 2004). When the initial tariff is lower than optimal, this relationship may reverse such that a decrease in the tariff rate will decrease optimal inspection intensity.

The relationship between the elasticity of m with respect to τ and the elasticity of $\frac{dW}{d\tau}$ with respect to τ determines the response of inspection intensity to the predetermined tariff and can be described as follows. A reduction in the predetermined tariff increases m , which reduces the marginal increase in welfare due to an additional unit of inspection intensity. On the other hand, a reduction in the tariff increases $\frac{dW}{d\tau}$, which increases the marginal increase in welfare due to an additional unit of inspection intensity. The overall impact of a reduction in the predetermined tariff on optimal inspection intensity therefore depends on the relative magnitude of these two effects. If the elasticity of m with respect to τ exceeds the elasticity of $\frac{dW}{d\tau}$ with respect to τ , then the inspection agency prefers to decrease inspection intensity in response to a decrease in the predetermined tariff.

Weight on Domestic Producer Surplus

When the tariff rate and inspection intensity are set jointly, inspection intensity is unresponsive to changes in the weight on domestic producer surplus – the tariff dominates inspection intensity as the most efficient policy instrument for shifting rents to the domestic production sector. If the tariff rate is predetermined, border inspection is the only instrument available, and inspection intensity is increasing in the weight on domestic producer surplus.

PROPOSITION 10.

When the tariff is predetermined, an increase in the weight on domestic producer surplus will increase optimal inspection intensity.

Proof. Differentiating equation (2.3.2) yields $\frac{dI}{d\lambda} = -\frac{\frac{dp}{dI}y}{\frac{d^2W}{dI^2}} > 0$.

As shown in the previous section, the optimal tariff is strictly increasing in the weight on domestic producer surplus. This implies that $\frac{dW}{d\tau}$ increases as the weight on domestic producer surplus increases. As shown in Figure 2 and 3, an increase in $\frac{dW}{d\tau}$ shifts the marginal cost of an additional unit of inspection intensity down and to the left and shifts the marginal net benefit of an additional unit of inspection intensity up and to the right. Therefore, when the weight on domestic producer surplus increases the inspection agency prefers to inspect imports more intensively.

The rate of response of inspection intensity to a change in the weight on domestic producer surplus depends on the response of domestic price to a change in inspection intensity $\frac{dp}{dI}$, as well as the size of the domestic production sector y .

Note that the responsiveness of domestic price depends on the size of the importing country. If the importer is small, then the full marginal price effect of border inspection $b_I + fh_I$ is passed through to the domestic price. This implies that border inspection is a less effective means of transferring surplus from consumers to producers as the market power of the importer increases.

Expected Marginal NIS Damage

When the tariff is set optimally inspection intensity is increasing in expected marginal damage. This result carries over when the tariff is predetermined.

PROPOSITION 11.

When the tariff is predetermined, an increase in expected marginal NIS damage will increase optimal inspection intensity.

Proof. Differentiating equation (2.3.2) yields $\frac{dI}{d\delta} = -\frac{mh_t - \frac{\partial m}{\partial p} \frac{dp}{dI}(q-h)}{\frac{d^2W}{dI^2}} > 0$.

PROPOSITION 11 shows that the inspection agency prefers to inspect more damaging imports more intensively. This relationship can also be derived from the adjusted-marginal-cost-adjusted-marginal-net-benefit equality presented graphically in Figure 2 and 3. The marginal cost of inspection intensity is decreasing in expected damage and the marginal net benefit is increasing in expected damage. An increase in expected damage therefore shifts the marginal cost curve down and to the right and shifts the marginal net benefit curve up and to the right, implying that an increase in expected damage unambiguously increases optimal inspection intensity. Note that the previous two propositions demonstrate that inspection intensity can increase due to both a genuine desire to provide protection from NIS damage and from protectionist motives.

Treatment Cost

In the previous section I show that optimal inspection intensity is decreasing in marginal treatment cost, whereas the optimal tariff may be increasing or decreasing

in treatment cost. When the tariff is predetermined, an increase in marginal treatment cost has an ambiguous impact on optimal inspection intensity.

PROPOSITION 12.

When the tariff is predetermined an increase in marginal treatment cost will have an ambiguous effect on optimal inspection intensity

Proof. Differentiating equation (2.3.2) yields

$$\frac{dI}{df} = - \frac{\overbrace{-mh_1}^{(-)} + \overbrace{(b_1 + fh_1)h}^{(+,-)} \left[\frac{d^2W}{d\tau^2} - \frac{\partial m}{\partial p} \frac{dp}{d\tau} \right] + \overbrace{\left[h_1 - \frac{\partial m}{\partial p} \frac{dp}{df} \frac{(b_1 + fh_1)}{m} \right]}^{(+)} \overbrace{\frac{dW}{d\tau}}^{(+,-)}}{\frac{d^2W}{dI^2}} \geq 0.$$

When the tariff is set optimally, inspection intensity adjusts to a change in treatment cost according to the first term, $-mh_1 < 0$. This term reflects the reduction in the marginal net benefit of an additional unit of inspection intensity. In Figure 2 and 3 this implies the marginal net benefit curve shifts down and to the left in response to an increase in marginal treatment cost.

The second term $(b_1 + fh_1)h \left[\frac{d^2W}{d\tau^2} - \frac{\partial m}{\partial p} \frac{dp}{d\tau} \right]$ captures the trade-off between

terms of trade and political economy motives for the optimal tariff as described in PROPOSITION 5. Since use of the tariff is constrained, this term influences optimal inspection intensity. Recall that when the importer is small, there is no protectionism ($\lambda = 1$), and the tariff is set optimally, this term goes to zero.

The final term $\left[h_1 - \frac{\partial m}{\partial p} \frac{dp}{df} \frac{(b_1 + fh_1)}{m} \right] \frac{dW}{d\tau}$ captures the shifts in marginal

cost and marginal net benefit of an additional unit of inspection intensity; the

direction of these shifts depends on the level of the predetermined tariff rate relative to the optimal tariff rate. Referring to Figure 2, if the tariff is higher than optimal an increase in marginal treatment cost shifts the marginal net benefit curve down and to the left by $h_1 \left[1 - \frac{\partial m}{\partial p} \frac{dp}{df} \frac{f}{m} \right] \frac{dW}{d\tau}$ and shifts the marginal cost curve up and to the left by $-b_1 \frac{\partial m}{\partial p} \frac{dp}{df} \frac{1}{m} \frac{dW}{d\tau}$. Therefore, if the tariff is higher than optimal then inspection intensity is more likely to decrease due to an increase in treatment cost.

Alternatively, referring to Figure 3, if the predetermined tariff is lower than optimal an increase in marginal treatment cost shifts the marginal benefit curve up and to the right by $h_1 \left[1 - \frac{\partial m}{\partial p} \frac{dp}{df} \frac{f}{m} \right] \frac{dW}{d\tau}$ and shifts the marginal cost curve down and to the right by $-b_1 \frac{\partial m}{\partial p} \frac{dp}{df} \frac{1}{m} \frac{dW}{d\tau}$. In this case, inspection intensity is more likely to increase due to an increase in marginal treatment cost. When the tariff is lower than optimal the inspection agency has greater incentive to increase domestic price compared to the case if the tariff is set optimally or higher than optimal.

Expected Infection Rate

As is the case when the tariff is set optimally, when the tariff is predetermined inspection intensity may be increasing or decreasing in the infection rate.

PROPOSITION 13.

When the tariff is predetermined an increase in the expected infection rate will have an ambiguous effect on optimal inspection intensity.

Proof. Differentiating equation (2.3.2) yields

$$\frac{dI}{dq} = \frac{\overbrace{-mh_{iq}(f-\delta)}^{(+,-)} - \overbrace{\frac{\partial m}{\partial p} \frac{dp}{dI} \delta(1-h_q)}^{(+,-)} + \overbrace{(b_l + fh_l) fh_q \left[\frac{d^2W}{d\tau^2} - \frac{\partial m}{\partial p} \frac{dp}{d\tau} \right]}^{(+,-)} + \overbrace{\left[h_{iq} - \frac{(b_l + fh_l)}{m} \frac{\partial m}{\partial p} \frac{dp}{dq} \right] \frac{dW}{d\tau}}^{(+,-)}}{\frac{d^2W}{dI^2}} \underset{\geq 0}{> 0}$$

As shown in PROPOSITION 13 the relationship between inspection intensity and the infection rate is ambiguous. The first term $-mh_{iq}(f-\delta)$, which depends on the marginal productivity of an additional unit of inspection intensity given a change in the infection rate h_{iq} , is ambiguous and corresponds to the case when the tariff is set optimally. The second term $-\frac{\partial m}{\partial p} \frac{dp}{dI} \delta(1-h_q)$ incorporates the Pigouvian component of the optimal tariff and has an ambiguous impact on optimal inspection intensity; an increase in the infection rate increases expected damage as well as expected detections. Once again, the third term $(b_l + fh_l) fh_q \left[\frac{d^2W}{d\tau^2} - \frac{\partial m}{\partial p} \frac{dp}{d\tau} \right]$ captures the trade-off between terms of trade and political economy motives for the optimal tariff as described in PROPOSITION 6.

The last term depends on whether or not the tariff is set lower or higher than optimal, according to the term $\left(h_{iq} - \frac{(b_l + fh_l)}{m} \frac{\partial m}{\partial p} \frac{dp}{dq} \right) \frac{dW}{d\tau}$. Note that if $h_{iq} > 0$ and the tariff is lower than optimal, this term is positive and inspection intensity is more likely to be increasing in the infection rate. Alternatively, if $h_{iq} > 0$ and the tariff is

higher than optimal, then this term is negative and inspection intensity is more likely to be decreasing in the infection rate.

2.4 Concluding Remarks

This chapter generalizes the theory of optimal border inspections presented in earlier work along a number of dimensions in a manner consistent with US agricultural border inspections for NIS. First, a political economy weight on domestic producer surplus is incorporated into the model. Second, I relax the small country assumption and allow world price to adjust to variation in the policy instruments. Third, I assume that detected imports are treated rather than destroyed. Fourth, I allow the detection rate to be nonlinear in the infection rate. Finally, in addition to an analysis of joint determination of tariffs and inspection intensity, I examine the characteristics of optimal border inspection intensity when the import tariff is constrained.

When tariffs and inspections are both set optimally I find that inspection intensity is set independent of political economy considerations, consistent with the notion that an import tariff is a more efficient policy instrument for transferring rents from consumers to producers. If the tariff is predetermined, optimal inspection intensity is a function of political economy considerations; I show that an increase in the welfare weight the government places on domestic producers will increase the politically optimal level of inspection intensity. Optimal inspection intensity is increasing in expected marginal NIS damage irrespective of the level of the tariff rate. When the tariff is predetermined, I find that the relationships between inspection

intensity and the tariff, the infection rate, and marginal treatment cost are ambiguous. All three of these variables influence domestic price, and as a consequence the optimal tariff policy takes these price effects into account. When use of the tariff is restricted, the inspection agency compensates by adjusting border inspection policy to offset these price effects.

3. Empirical Framework

In this chapter, I introduce an empirical framework for analysis of the extent to which US border inspections for NIS are implemented in a trade distorting manner, versus implemented to address NIS risk. In the first section I review the prior empirical trade literature evaluating the use of trade policy to protect domestic producers from import competition. In the second section I outline the framework for the empirical analysis, guided by the theoretical model presented in the previous chapter. I propose an econometric specification of the implicit expression for the politically optimal border inspection intensity. Reduced form and structural specifications of the econometric model are presented. I derived predictions for the reduced form model directly from the theory. Similarly, the structural model is derived directly from the theory allowing me to identify two parameters of interest: the weight on domestic producer surplus and expected NIS damages implied by the actions of the inspection agency.

3.1 Prior Literature

The empirical trade literature examining the formation of NTBs has focused on industry-level determinants of NTBs in the US manufacturing sector. The literature has addressed the simultaneity of imports and NTBs, and has tended to focus on political factors relevant to NTB protection. Coverage ratios based on the portion of goods within an industry that are subject to NTBs have been used as a measure of the stringency of NTBs faced by individual industries. Until recently, the

literature has assumed that the export supply of foreign goods is perfectly elastic; this assumption is relaxed by Broda, Limao, and Weinstein (2008).

Ray (1981) examines the sequential formation of tariffs and NTBs in the US manufacturing industry in 1970. An index of NTBs is constructed based on fifteen types of trade restrictions weighted by their relative effectiveness in restricting imports. Ray finds that the level of tariff protection has a positive impact on the stringency of NTBs and concludes that industries that are able to secure higher tariff protection are also able to secure higher non-tariff protection.

Trefler (1993) examines the relationship between NTBs and US manufacturing imports (measured as an import penetration ratio) in 1983.¹² Econometric results indicate that the impact of import penetration on NTBs is statistically insignificant but the change in import penetration over a three year period has a positive and statistically significant impact on NTBs. In the import penetration equation, NTBs are found to have a negative and statistically significant effect on import levels, a result that is robust to both the simultaneous equations approach and the single equation approach.

Lee and Swagel (1997) follow the approach of Trefler (1993) but use a sample consisting of multiple countries (both developed and developing) and a cross-section of manufacturing industries. Using a panel dataset allows the authors to control for unobserved heterogeneity by including industry and country fixed effects. As in Ray (1981), Lee and Swagel (1997) find that both the tariff rate and the import penetration ratio have a positive impact on NTBs. Lee and Swagel (1997) conclude that

¹² The import penetration ratio is measured as imports divided by domestic consumption (domestic consumption is imports plus domestic production)

industries facing relatively more import competition are more likely to receive NTB protection.

Goldberg and Maggi (1999) and Bandyopadhyay and Gawande (2000) test the Grossman and Helpman (1994) political economy model of trade protection. The variables of interest in these models are the import demand elasticity, the import penetration ratio, and a dummy indicating whether or not the industry is organized politically and can effectively lobby the government for trade protection.¹³ The Grossman-Helpman model predicts that the impact of import penetration on tariffs will depend on whether or not the industry lobbies the government for trade protection: if the industry is organized, import penetration will have a negative impact on protection whereas if the industry is not organized, then import penetration should have a positive impact on protection. The Grossman-Helpman model therefore leads to a specification where the import penetration and the ‘lobbying’ variables are interacted. A contribution of the Goldberg and Maggi (1999) and the Gawande and Bandyopadhyay (2000) papers is that they control for this interaction and find strong support for the Grossman-Helpman predictions.¹⁴

Broda, Limao, and Weinstein (2008) are the first to test the optimal tariff theory using export supply elasticity estimates. They examine tariff formation in countries that are not members of the WTO, as well as the formation of most favored nation (MFN) tariffs, statutory tariffs, and NTBs in the US. As opposed to the trade policy studies cited above, Broda, Limao, and Weinstein (2008) use the entire cross-

¹³ The import penetration ratio now refers to the ratio of imports to domestic production, rather than the ratio of imports to domestic consumption as in the previous studies.

¹⁴ Both papers define industry organization on the basis of whether or not campaign contributions for that industry exceed a certain threshold. Their measure of lobbying therefore captures the bribery aspect of political influence but does not account for other mechanisms of political lobbying.

section of imported goods in each country. They find that tariffs in non-WTO countries are positively correlated with inverse export supply elasticities – strong evidence in support of the optimal tariff theory. In the US, they find that MFN tariff rates (which are constrained by trade agreements) are not affected by importer market power whereas market power has a positive impact on statutory tariffs and NTBs. All results are robust to the inclusion of import demand elasticity and import penetration ratios.

3.2 *Empirical Model*

The theoretical model developed in Chapter 2 presents an implicit expression for optimal inspection intensity:

$$(3.1.1) \frac{dW}{dI} = -(k - h_I(I, q)\delta) + \frac{dp}{dI} \left\{ -1 + (\lambda - 1) \frac{y}{m} - \frac{\eta}{p} [\tau - kI - \delta(q - h(I, q))] \right\} = 0$$

where $\frac{dp}{dI} = \frac{(b_I(I) + fh_I(I, q))\omega p}{\eta p_w + \omega p} \geq 0$. Note that inspection intensity I enters

equation (3.1.1) directly and indirectly through the detection rate, $h(I, q)$, the marginal detection rate, $h_I(I, q)$, and the marginal indirect trade cost due to inspections, $b_I(I)$. Inspection intensity is an index of inspection effort, which may vary by the fraction of goods selected for a physical inspection, the sampling rate within the subset of goods selected for a physical inspection, the method of selecting the sample, as well as the effort expended to detect NIS once a sample has been selected. Therefore, as it is defined in this model, inspection intensity is not directly observable.

While inspection intensity is not observed directly, the average detection rate – based on the volume of inspected imports – is observed. The average detection rate is a function of inspection intensity and the average infection rate per kilogram of imports. The marginal detection rate is also unobserved. However, the following assumption about the likelihood of detecting NIS generates an expression for the marginal detection rate that is a function of the expected infection rate as well as the expected detection rate. Adopting an explicit functional form for the detection rate permits specification of a structural econometric model.

As mentioned in Chapter 2, the statistical literature on sampling for rare individuals demonstrates that the probability of detecting at least one actionable pest at a sampling rate of less than 5 percent can be approximated by an exponential distribution (Venette, Moon, and Hutchinson 2002 refer to it as a Poisson distribution). Since US agricultural inspectors sample at a rate of less than 5 percent from the total import volume selected for a physical inspection, the exponential distribution is appropriate in this empirical application. Assuming an exponential distribution, the likelihood of detecting at least one actionable NIS can be written as a function of inspection intensity and the expected infection rate as follows:¹⁵

$$(3.1.2) \quad h(I, q) = 1 - e^{-qI}.$$

The associated partial derivative with respect to inspection intensity, $h_I = q(1 - h)$, is used to approximate the marginal detection rate in the structural model that follows.

¹⁵ As mentioned previously, inspection intensity is a function of the sampling rate as well as the efficacy of the inspection procedure. Efficacy may include factors such as the choice of sample (random versus tailgate) as well as the effort expended to detect NIS within a given sample.

As presented in the theoretical model, total trade cost due to inspections is the sum of border costs as well as the cost of treating detected imports $b(I) + fh(I, q)$. Border costs due to inspections $b(I)$ are unobserved. For the purposes of the structural model I assume that border costs due to inspections are proportional to detections such that $b(I) = bh(I, q)$. Imports that are inspected have a positive expected infection rate by assumption; this implies $h_i > 0$ and an increase in inspection intensity increases total trade costs associated with border inspections. Given these assumptions total expected trade cost due to inspections is written as $(b + f)h(I, q) = ah(I, q)$.

The structural model is estimated using a range of plausible values for a . The lower bound on trade cost due to inspections is set at the average per kilogram cost of fumigating vegetables by methyl bromide. The upper bound on total trade cost due to inspections is set at 1 percent of the average domestic price of the imported commodity. Using a price-wedge approach, Yue, Beghin, and Jensen (2006) estimate ad valorem equivalents of technical barriers to trade on Japanese imports of US apples which range between 39 percent and 60 percent for the years 2000 through 2002. The ad valorem equivalent derived in Yue, Beghin, and Jensen includes compliance costs due to harvesting, packing, and shipping requirements as well as any border costs incurred. Liu and Yue (2009) estimate ad valorem tariff equivalents for cut flower imports (which are highly perishable) into Japan to range from 81 percent to 94 percent for the years 2002 through 2007. Given the large ad valorem equivalent estimates reported in these studies, an upper bound on total trade cost due

to inspections of 1 percent of domestic price seems reasonable. Estimating the model over a range of values for a permits a sensitivity analysis of the parameter estimates.

In the context of the theoretical model presented in Chapter 2, the total import tax can be rewritten as the sum of a user fee u and the ad valorem tariff τ . For the purposes of the empirical analysis, I assume that the user fee is set to recover inspection cost so that, on average, $u = kI$. This assumption implies that, on the margin, cost recovery does not influence the inspection agency's choice of inspection intensity of an individual commodity during a given week. This is consistent with US agricultural border inspections, where the cost of inspecting agricultural commodities is recovered through a user fee charged on a per shipment basis, independent of the inspection effort expended on any particular shipment (GAO 2008).¹⁶ The total cost of inspecting imports is therefore recovered by total user fees collected throughout the year.

Agricultural commodities arriving at US ports of entry are subjected to a physical inspection if they are thought to potentially harbor NIS. Within a commodity, assessment of NIS risk may also be based on country of origin and within a certain country of origin, by particular growers and/or shippers. The US operates a number of pre-clearance and precautionary treatment programs and a number of vegetable commodities imported from Mexico are included in the NARP (formerly the Border Cargo Release Program). Shipments entering as a part of the NARP are considered low-risk shipments and are often tied to specific growers in Mexico. Since the expected infection rate of these imports is low, imports entering

¹⁶ The inspection fee is \$492 per arrival; \$110 for the arrival of cargo laden in Canada or Mexico (GAO 2008). APHIS collects user fees on behalf of CBP. APHIS transfers a portion of the user fees back to CBP based on an estimate of the cost of inspecting non-propagative agricultural commodities.

under the NARPP are subject to compliance (rather than surveillance) monitoring and are thus physically inspected at a lower frequency. For the purposes of the empirical analysis, I assume the total import volume of a given commodity is divided into two groups: the volume of low-risk imports that are inspected infrequently because they enter under a special program, denoted $m^L(p)$, and the volume of high-risk imports that are inspected routinely on arrival, denoted $m^H(p)$, where $m(p) = m^H(p) + m^L(p)$. The rate at which low risk imports are inspected is low, so I treat them as not being inspected at all.

Incorporating these assumptions into the theoretical framework, equation (3.1.1) is rewritten according to the following steps. First, substitute in $u = kI$ and substitute $m^H(p)$ for the high risk inspected imports $m(p) = m^H(p) + m^L(p)$:

$$(3.1.3) \quad -m^H(k - \delta h_t) - \frac{dp}{dI} m + \frac{dp}{dI} (\lambda - 1) y + \frac{\partial m}{\partial p} \frac{dp}{dI} \tau - \frac{\partial m^H}{\partial p} \frac{dp}{dI} \delta (q - h) = 0$$

where the impact of inspection effort on the price of inspected imports is fully passed through to the price of imports which are not inspected as well as the price of

domestically produced goods. Next, normalize the expression by $\frac{m\eta}{p} \frac{dp}{dI}$, substitute

the domestic price response to inspection intensity with $\frac{dp}{dI} = \frac{(b_t + fh_t)\omega p}{\eta p_w + \omega p}$, and

substitute the marginal impact on total trade costs due to inspections with

$$b_t + fh_t = aq(1 - h):$$

$$(3.1.4) \quad -\frac{m^H}{m} \left(\frac{p_w}{\omega} + \frac{p}{\eta} \right) \frac{(k - \delta q(1 - h))}{aq(1 - h)} - \frac{p}{\eta} + (\lambda - 1) \frac{y}{m} \frac{p}{\eta} - \tau + \delta (q - h) = 0.$$

Finally, substitute for the world price $p^w = p - \tau - ah$:

$$(3.1.5) \quad -\frac{m^H}{m} \left(\frac{p - \tau - ah}{\omega} + \frac{p}{\eta} \right) \frac{(k - \delta q(1-h))}{aq(1-h)} - \frac{p}{\eta} + (\lambda - 1) \frac{y}{m} \frac{p}{\eta} - \tau + \delta(q - h) = 0.$$

The first order condition presented in equation (3.1.5) serves as the basis for the reduced form and structural econometric analyses that follow.

3.3 Econometric Specification

This section will present reduced form and structural form specifications of equation (3.1.5). A description of the data is presented in the following chapter. The models are estimated for five categories of vegetable imports into the US, including bean/pea, broccoli/cauliflower, onion, pepper, and tomato using three years of weekly data. The econometric specifications are based on observable variables, including the detection rate, total import volume, inspected import volume, shipments of domestic production, the domestic import price, and the tariff rate. Seasonal trade elasticities, where season is defined by the Harmonized Tariff Schedule of the US, are estimated separately.

Although the detection rate is observed as an outcome of the inspection process, the expected infection rate is not observed. Observing an expected infection rate would require a set of observations based on randomly conducted inspections with sufficient coverage over time and across US ports. APHIS does conduct more thorough random inspection of agricultural imports through its Agricultural Quarantine Inspection Monitoring (AQIM) program. However, this data is

unavailable and the coverage of AQIM both across ports and across commodities is not complete.

The expected damage due to admitted NIS is also unobserved. As described in the theoretical model, expected damage per admitted pest captures the probability that a damaging pest becomes established in the importing country. It therefore includes the extent of the range over which NIS may become established as well as the damage within that range. APHIS has conducted a small number of commodity-specific risk assessments primarily dealing with imported commodities that have been subject to recent regulatory action, such as avocado imports from Mexico or clementine imports from Spain. These risk assessments provide qualitative, rather than quantitative, assessments of potential damage. APHIS has conducted a number of pest-specific risk assessments. Once again, these assessments assess potential damage in a qualitative manner and do not rank the susceptibility of specific commodities.

3.3.1 Reduced Form Specification

The econometric analysis begins with a reduced form specification based on the model developed in the previous section. As mentioned above, the observed variables include commodity-specific weekly observations of the detection rate, the import penetration ratio, the share of imports inspected, the domestic price, the tariff rate, and seasonal estimates of import demand and export supply elasticities. In previous political economy trade models, import demand elasticities have played an important role in identifying political economy parameters. These studies are cross-

sectional analyses conducted at the industry level, typically manufacturing.

Identification of the political economy parameters relies on an assumption that the government places equal weight on the welfare of different sectors within the industry.

This study assesses the determinants of a non-tariff barrier implemented to address an expected NIS externality that is unobserved. I control for the major source of unobserved heterogeneity in the expected infection rate and expected NIS damage by conducting the analysis at the commodity level. Further, conducting a commodity specific analysis allows the political economy variables to vary by commodity.

The reduced form model is guided by the implicit expression for inspection intensity written in equation (3.1.5). The detection rate is the dependent variable and the inverse import penetration ratio, the inverse import demand elasticity, the domestic price of imports, the inverse export supply elasticity, the tariff rate, and the share of total imports inspected are the independent variables. The reduced form model is written as follows:

$$(3.2.1) \quad h_{c,t} = \alpha_{1c} + \alpha_{2c} \frac{y_{c,t}}{m_{c,t}} + \alpha_{3c} \frac{1}{\eta_{c,t}} + \alpha_{4c} p_{c,t} + \alpha_{5c} \frac{1}{\omega_{c,t}} + \alpha_{6c} \tau_{c,t} + \alpha_{7c} \frac{m_{c,t}^H}{m_{c,t}} + \varepsilon_{c,t}$$

where $\varepsilon_{c,t}$ is an error term, c denotes commodity, and t denotes week. Note that this analysis assumes the infection rate, NIS damages, the weight on domestic producer surplus, inspection costs, and the trade costs due to inspections are constant for each commodity. The model is estimated both with and without a winter dummy variable in order to control for unobserved heterogeneity, which may be due to potential variation in the realized infection rate as well as expected damage.

Predicted signs on these coefficients are derived as follows. In Chapter 2, the implicit expression for optimal inspection intensity was written in terms of adjusted-marginal-cost-adjusted-net-marginal-benefit (see equation (2.3.6)). Ignoring the assumption that $b(I) = bh(I, q)$, the implicit expression for optimal inspection intensity presented in equation (3.1.5) can be rewritten as follows:

$$(3.2.2) \quad \left(b_I + \frac{m^H}{m} k \right) - b_I \left\{ \left(1 - \frac{dp}{d\tau} \right) + \frac{dp}{d\tau} (\lambda - 1) \frac{y}{m} - \frac{dp}{d\tau} \frac{\eta}{p} [\tau - \delta(q - h)] \right\} \\ = h_I \left[\left(\frac{m^H}{m} \delta - f \right) + f \left\{ \left(1 - \frac{dp}{d\tau} \right) + \frac{dp}{d\tau} (\lambda - 1) \frac{y}{m} - \frac{dp}{d\tau} \frac{\eta}{p} [\tau - \delta(q - h)] \right\} \right]$$

where the left hand side represents the adjusted marginal cost and the left hand side represents the adjusted net marginal benefit of an additional unit of inspection intensity.

The primary coefficient of interest is the coefficient on the inverse import penetration ratio $\frac{y}{m}$. Examination of equation (3.2.2) indicates that an increase in the inverse import penetration ratio decreases the marginal cost and increases the net marginal benefit of an additional unit of inspection intensity. Since the detection rate is increasing in inspection intensity, all else equal, we expect that an increase in the inverse import penetration ratio will increase the detection rate.

The reduced form regressions control for variation in domestic prices. Note from equation (3.2.2) that domestic price enters the model directly as well as indirectly through $\frac{dp}{d\tau}$. In general, the domestic price may have a positive or negative impact on inspection intensity. The expected sign of the coefficient on domestic price is therefore ambiguous.

The inverse import demand elasticity and inverse export supply elasticity are included in the reduced form model to control for seasonal variation in the responsiveness of domestic price to policy instruments. Note that an increase in the inverse import demand elasticity or an increase in the inverse export supply elasticity increases the responsiveness of domestic price to the tariff, $\frac{dp}{d\tau} = \frac{\omega p}{\omega p + \eta p^w}$. The impacts of both inverse elasticities on the adjusted marginal cost and adjusted marginal net benefit of an additional unit of inspection intensity are therefore ambiguous. For example, an increase in the inverse import demand elasticity or an increase in the inverse export supply elasticity decreases the terms of trade and increases the political economy motives for inspection intensity. Given this ambiguity, the coefficients on the inverse import demand elasticity and the inverse export supply elasticity may be positive or negative.

A cursory examination of equation (3.2.2) indicates that an increase in the tariff increases the marginal cost and decreases the net marginal benefit of an additional unit of inspection intensity. This suggests that the two policy instruments are substitutes and the inspection agency will choose to inspect those imports with lower tariff rates more intensively. Of course, this ignores the fact that $\frac{dp}{d\tau}$ is a function of the tariff and, as shown in the theoretical model, the response of inspection intensity to an increase in the tariff rate may be positive or negative depending on the initial level of the tariff rate. Therefore, the reduced form coefficient on the tariff rate may be positive or negative.

Finally, the share of imports that are inspected, $\frac{m^H}{m}$, is included in the reduced form model. Since this variable reflects variation in the source (either country of origin or grower) of imports, it serves as a proxy for potential variation in the infection rate. Examination of equation (3.2.2) indicates that an increase in the share of imports inspected increases the marginal cost and also increases the marginal benefit due to an additional unit of inspection intensity and will therefore have an ambiguous impact on the detection rate. As a consequence, the coefficient on the share of imports that are inspected may be positive or negative.

The reduced form specification presented in this section permits an analysis of the correlations between the detection rate and the observed variables in the model. Since the primary objective of the empirical analysis is to examine the use of border inspections as a distortionary tool, the relationship between the detection rate and the inverse import penetration ratio is of particular interest. In the following section I propose a structural specification of the model that identifies the implied weight the inspection agency places on domestic producers relative to consumers and other components of the social welfare function. Additionally, the structural model identifies expected NIS damage as implied by the actions of the inspection agency.

3.3.2 Structural Specification

A structural model based on the first order condition for optimal inspection intensity is specified in this section. The structural analysis explicitly controls for the relationships among the variables as suggested by the theoretical model and is

specified as follows. The inspection agency's implicit choice of inspection intensity – described by the expression in equation (3.1.5) – of commodity c during week t is written as a function of the observed variables and parameters:

$$(3.3.1) \quad G(\boldsymbol{\theta}) = (\lambda_c - 1) \left[\frac{y_{c,t}}{m_{c,t}} \frac{p_{c,t}}{\eta_{c,t}} \right] - \frac{k_c}{q_c} \left[\frac{1}{a(1-h_{c,t})} \left(\frac{p_{c,t}}{\eta_{c,t}} + \frac{p_{c,t} - \tau_{c,t} - ah_{c,t}}{\omega_{c,t}} \right) \frac{m_{c,t}^H}{m_{c,t}} \right] - \delta_c \left[h_{c,t} - \frac{1}{a} \left(\frac{p_{c,t}}{\eta_{c,t}} + \frac{p_{c,t} - \tau_{c,t} - ah_{c,t}}{\omega_{c,t}} \right) \frac{m_{c,t}^H}{m_{c,t}} \right] + \delta_c q_c - \left[\frac{p_{c,t}}{\eta_{c,t}} + \tau_{c,t} \right] = 0$$

where $G(\boldsymbol{\theta})$ is a generalized residual, the observed variables are contained in square brackets, and the parameters are outside of the square brackets. A range of plausible values of the parameter a are imposed on the model and $\boldsymbol{\theta}$ denotes the 4×1 vector of commodity-specific parameters to be estimated:

$$(3.3.2) \quad \boldsymbol{\theta} = \left(\frac{k_c}{q_c}, \delta_c, \delta_c q_c, (\lambda_c - 1) \right)'$$

Note that this assumes that the infection rate, expected damage per admitted pest, weight on domestic producer surplus, inspection cost, and trade cost due inspections are constant for each commodity. Consistent estimates of the parameters in (3.3.2) are obtained by the generalized method of moments (GMM). A set of population moment conditions is derived using instrumental variables \mathbf{Z} , which are orthogonal to the residual $G(\boldsymbol{\theta})$ such that:¹⁷

¹⁷ Identification of the expected infection rate parameter relies on an assumption that the inspection agency has an unbiased estimate of the expected infection rate which is constant throughout the year. The observed detection rate is the outcome of inspection intensity, $I_{c,t}$ and realizations of the infection rate which can be written as $\bar{q}_c + v_{c,t}$, where $v_{c,t}$ represents random variation around the expected infection rate and $E[v_{c,t}] = 0$. Since $v_{c,t}$ enters the error term, I use a heteroskedasticity and autocorrelation-robust variance-covariance matrix as described in the text.

$$(3.3.3) \quad E[\mathbf{Z}'G(\boldsymbol{\theta})] = 0$$

where E is the expectation operator and the $T \times k$ matrix \mathbf{Z} consists of a set of predetermined variables in $G(\boldsymbol{\theta})$. Provided that $k \geq 4$, the GMM estimator is defined by:

$$(3.3.4) \quad \boldsymbol{\theta}^T = \arg \min_{\boldsymbol{\theta}} \{g^T(\boldsymbol{\theta})' \mathbf{W}^T g^T(\boldsymbol{\theta})\}$$

where $g^T(\boldsymbol{\theta}) = \frac{1}{T} \sum_{t=1}^T (\mathbf{Z}'G(\boldsymbol{\theta}))$ and \mathbf{W}^T is a $k \times k$ positive semi definite weighting matrix. I use the heteroskedasticity and serial correlation robust variance-covariance matrix as proposed by Newey and West (1987).¹⁸

As described above, the econometric analysis is restricted to five vegetable commodities including broccoli/cauliflower, beans/peas, onion, pepper, and tomato. Estimating a separate model for each commodity controls for heterogeneity in the expected infection rate and expected NIS damage across commodities. For each of the vegetable commodities, I estimate four different models corresponding to different assumed trade costs due to inspections a . In addition, two alternative sets of instrumental variables are used. This implies that a total of forty models are estimated: five commodities \times four assumed trade costs \times two sets of instrumental variables. In addition, twenty models that allow for seasonal heterogeneity in the expected damage, infection rate, and inspection cost parameters are estimated using

¹⁸ The estimated weighting matrix is obtained by a two-step procedure. In the first step, starting values for the parameter vector and the weighting matrix are used to obtain a consistent variance-covariance matrix estimate by the Newey and West (1987) method. A Bartlett kernel with a bandwidth of 4 is used. In the second step, the consistent estimate of the weighting matrix from the previous step is used to obtain updated estimates of the weighting matrix and parameters. This second step is iterated until convergence criteria are met. The iterated procedure is performed in Matlab using code adapted from Kyriakoulis (<http://www.kostaskyriakoulis.com/gmmgui.html>).

the set of nonlinear instrumental variables interacted with winter and summer season dummies.

Nonlinear instruments

The first set of instruments consists of a constant and nonlinear combinations of the observed values lagged one and two years (52 and 104 weeks) such that:

$$(3.3.5) \quad \mathbf{Z} = \begin{bmatrix} 1, \frac{\bar{y}_{c,t-52}}{\bar{m}_{c,t-52}} \frac{\bar{p}_{c,t-52}}{\eta_{c,t}}, \frac{\bar{y}_{c,t-104}}{\bar{m}_{c,t-104}} \frac{\bar{p}_{c,t-104}}{\eta_{c,t}}, \frac{1}{a} \left(\frac{\bar{p}_{c,t-52}}{\eta_{c,t}} + \frac{\bar{p}_{c,t-52} - \bar{\tau}_{c,t-52}}{\omega_{c,t}} \right), \\ \frac{1}{a} \left(\frac{\bar{p}_{c,t-104}}{\eta_{c,t}} + \frac{\bar{p}_{c,t-104} - \bar{\tau}_{c,t-104}}{\omega_{c,t}} \right), \frac{\bar{p}_{c,t-52}}{\eta_{c,t}} + \bar{\tau}_{c,t-52}, \frac{\bar{p}_{c,t-104}}{\eta_{c,t}} + \bar{\tau}_{c,t-104} \end{bmatrix}$$

where $\bar{z}_{c,t-j}$ denotes the average value of the variable $z_{c,t}$ computed over the weeks $j-1, j$, and $j+1$. The lagged values are constructed using three week averages in order to smooth out short-term fluctuations in prices and quantities.

Since these instruments are predetermined at time t they satisfy the orthogonality condition. Further, they are correlated with the elements of $G_0(\boldsymbol{\theta})$. Since they are observed for a number of years outside of the sample period, lagged values of the domestic price, the tariff rate, and the inverse import penetration ratio are available. An assumption of the empirical analysis is that the seasonal export supply and import demand elasticities are constant across years. This, combined with the fact that the elasticities are estimated based on 1993 through 2004 calendar year data, implies the elasticities used in this analysis are predetermined for fiscal years 2005 through 2007.

Linear instruments

The second set of instruments consists of a constant, inverse trade elasticities, $\frac{1}{\eta_{c,t}}$ and $\frac{1}{\omega_{c,t}}$, and the variables $p_{c,t}$, and $\frac{y_{c,t}}{m_{c,t}}$ lagged one and two years (52 and 104 weeks) such that:

$$(3.3.6) \quad \mathbf{Z} = \left[1, \frac{1}{\eta_{c,t}}, \frac{1}{\omega_{c,t}}, \frac{\bar{y}_{c,t-52}}{\bar{m}_{c,t-52}}, \bar{p}_{c,t-52}, \frac{\bar{y}_{c,t-104}}{\bar{m}_{c,t-104}}, \bar{p}_{c,t-104} \right]$$

where $\bar{z}_{c,t-j}$ denotes the average value of the variable $z_{c,t}$ computed over the weeks $j-1, j$, and $j+1$. As with the previous set of instruments, these instruments are predetermined and satisfy the orthogonality conditions. Compared to the set of nonlinear instruments, the set of linear instruments is less correlated with $G_0(\boldsymbol{\theta})$ and as a consequence the parameter estimates, although consistent, are less efficient. This set of instruments is used in order to assess the robustness of the parameter estimates using the nonlinear set of instruments.

Terms of Trade

The implicit expression for inspection intensity presented in equation (3.3.1) includes estimates of finite export supply elasticities and therefore incorporates a terms of trade motive into the determination of inspection intensity. A competing behavioral model would suggest that market power, or the terms of trade motive, is not an important determinant of inspection intensity – this is equivalent to imposing an assumption that $\omega = \infty$. Under this assumption, the implicit expression for optimal inspection intensity is written as:

$$(3.3.7) \quad G(\boldsymbol{\theta}) = (\lambda_c - 1) \begin{bmatrix} \frac{y_{c,t}}{m_{c,t}} \frac{p_{c,t}}{\eta_{c,t}} \end{bmatrix} - \frac{k_c}{q_c} \begin{bmatrix} 1 & \frac{p_{c,t}}{\eta_{c,t}} \frac{m_{c,t}^H}{m_{c,t}} \end{bmatrix} \\ - \delta_c \begin{bmatrix} h_{c,t} - \frac{1}{a} \frac{p_{c,t}}{\eta_{c,t}} \frac{m_{c,t}^H}{m_{c,t}} \end{bmatrix} + \delta_c q_c - \begin{bmatrix} \frac{p_{c,t}}{\eta_{c,t}} + \tau_{c,t} \end{bmatrix} = 0$$

Estimation of the parameters of this model $\boldsymbol{\theta} = \left(\frac{k_c}{q_c}, \delta_c, \delta_c q_c, (\lambda_c - 1) \right)'$ is based on an

alternative set of instruments, once again imposing the assumption that $\omega = \infty$:

$$(3.3.8) \quad \mathbf{Z} = \begin{bmatrix} 1, \frac{\bar{y}_{c,t-52}}{\bar{m}_{c,t-52}} \frac{\bar{p}_{c,t-52}}{\eta_{c,t}}, \frac{\bar{y}_{c,t-104}}{\bar{m}_{c,t-104}} \frac{\bar{p}_{c,t-104}}{\eta_{c,t}}, \frac{1}{a} \frac{\bar{p}_{c,t-52}}{\eta_{c,t}}, \\ \frac{1}{a} \frac{\bar{p}_{c,t-104}}{\eta_{c,t}}, \frac{\bar{p}_{c,t-52}}{\eta_{c,t}} + \bar{\tau}_{c,t-52}, \frac{\bar{p}_{c,t-104}}{\eta_{c,t}} + \bar{\tau}_{c,t-104} \end{bmatrix}.$$

Strictly speaking, this model restricts the behavior of the inspection agency to that of a small importer and is therefore nested in the more general model that allows for a terms of trade motive. Note, however, that the restricted model has the same number of parameters and moment conditions as the unrestricted model and standard hypothesis tests based on restrictions on the parameters of the model do not apply. Further, the moment conditions cannot be partitioned into subsets corresponding to the terms of trade and the non-terms of trade determinants of optimal inspection intensity. This implies that a likelihood ratio-type hypothesis test based on nested moment conditions – as suggested by Eichenbaum, Hansen, and Singleton (1988) – is not applicable. Rather than conducting formal nested hypothesis tests, the two competing models are evaluated based on the over-identifying restrictions imposed by the two models. Eichenbaum (1989) conducts a similar evaluation of production level versus production cost smoothing models of inventory investment.

Interpretation of Structural Parameters

Once again, the objective of this empirical analysis is to examine the use of border inspections as a trade-distorting instrument. Given this objective, the primary parameter of interest is the implied weight the inspection agency places on domestic producer welfare λ , relative to other components of the social welfare function. A weight greater than one suggests that the inspection agency places greater value on a dollar of producer surplus as compared to a dollar of consumer surplus (and other components of welfare). An estimated weight that cannot be distinguished from one implies that the inspection agency is not using inspections in a distortionary manner. It also follows that an estimated weight less than one implies the inspection agency places less weight on domestic producer welfare relative to other components of the social welfare function.

The estimated weight on domestic producer surplus identifies the use of border inspections as a distortionary policy instrument, conditional on an expected level of NIS damage. An outcome of the structural model is an estimate of expected NIS damage δq . This parameter captures a revealed expectation of NIS damage, which may be influenced by lobbying by environmental and agricultural producer groups, implied by the behavior of the inspection agency. Since inspection intensity is positive for the set of commodities considered in this analysis, we expect the inspection agency to behave as if expected NIS damage is positive, which implies $\delta q > 0$. Estimates of expected damage close to or equal to zero for any one commodity category suggest that the inspection agency perceives potential damage associated with imports of that commodity as low.

3.4 Concluding Remarks

Both reduced form and structural models are presented in this chapter. The following chapter presents a description of the data used to estimate these models. Predicted signs on the reduced form coefficients are derived directly from the theory. With the exception of the inverse import penetration ratio, the predicted signs on the reduced form coefficients are ambiguous. Interpreting these coefficients within the context of the theory is therefore difficult.

As mentioned in the review of the empirical trade literature at the beginning of this chapter, a number of previous studies – in particular empirical tests of the Grossman and Helpman (1994) model (Goldberg and Maggi 1999; Bandyopadhyay and Gawande 2000) – often examine the formation of non-tariff barriers. These analyses estimate structural parameters using measures of the stringency of non-tariff barriers to trade based on theoretical models of tariff formation. As presented in this chapter, the predictions of a model of tariff formation do not necessarily carry over to models of non-tariff barriers. In contrast, the structural model presented in this chapter is derived directly from a theoretical model of border inspections.

4. Description of the Data

In this chapter, I describe the data used in the econometric analysis. The estimation uses 156 weekly observations of commodity-level variables spanning fiscal year 2005 thru fiscal year 2007. Weekly observed variables include detections of NIS, domestic prices, tariff rates, shipments of domestic production, the volume of total imports, and the volume of inspected imports. Seasonal import demand and export supply elasticities are estimated based on the method introduced by Feenstra (1994).

The analysis proceeds in two stages. First, seasonal/quarterly import demand and export supply elasticities are estimated based on the method developed by Feenstra (1994). In the second stage, trade elasticity estimates are combined with US border inspection and trade/production data to evaluate the border inspection model.

4.1 Trade Elasticity Estimates

Recent work in the empirical trade literature has developed a methodology for estimating trade elasticities using data readily available in international trade databases. The method, introduced by Feenstra (1994) and further developed by Broda and Weinstein (2006), estimates trade elasticities given an assumption that elasticities are constant across supplying countries as well as time. Elasticity estimates are based on annual observations of import prices and import volumes differentiated by country of origin. The data is first-differenced with respect to time

and a reference country; this eliminates effects which are constant across time and exporters.

Since import prices and import quantities are endogenous variables, identification of import demand and export supply elasticities relies on exogenous cross-sectional heterogeneity in the variance and covariance of the differenced import price and import quantity variables. This is an application of ‘identification through heteroskedasticity’ as described by Rigobon (2003) – identification is achieved under the assumption that relative shocks to import demand and export supply across trading partners are uncorrelated.¹⁹

For the purposes of the current empirical analysis, quarterly or seasonal trade elasticity estimates are derived for each of the commodity categories listed above. Quarterly or seasonal elasticity estimates capture different import demand and export supply conditions which may exist due to variation in consumer preferences through the course of a year as well as variation in domestic and foreign growing seasons. The definition of season corresponds to seasonal classifications as defined in the Harmonized Tariff Schedule (HTS) of the US. In cases where the HTS classification of commodities does not vary by season of entry, quarterly elasticities are estimated. Estimation of trade elasticities is based on monthly observations of import price and import volumes differentiated by country of origin for the period 1993 thru 2004 as provided by the US International Trade Commission (USITC).²⁰ Between 1993 and

¹⁹ Broda and Weinstein (2006) and Broda, Limao, and Weinstein (2008) provide detailed descriptions of the methodology introduced by Feenstra (1994).

²⁰ In some instances the Feenstra (1994) method generates elasticity estimates of the wrong sign. In these cases, Broda and Weinstein (2006) perform a grid search over a restricted set of parameters, such that the import demand elasticity does not exceed 132. I also adopt this approach; η and $1/\omega$ are restricted to be less than 132 and 0.0079 respectively.

2004, 33 countries exported tomatoes, 64 countries exported peppers, 49 countries exported onions, 27 countries exported beans/peas, and 15 countries exported broccoli/cauliflower to the US. I follow Feenstra (1994) and choose the largest exporter, Mexico in all commodity categories, as the reference country.

Recent estimates of trade elasticities suggest that the export supply of fruit and vegetable commodities is relatively inelastic as compared to other imports (including manufactured goods). Broda, Limao, and Weinstein (2008) report annual US export supply elasticity estimates for seven of the eight commodity categories analyzed in this paper. When compared to all commodity groups (including manufacturing and agricultural), Broda, Limao, and Weinstein (2008) find that the onion and broccoli/cauliflower categories fall into the highly inelastic export supply category and the bean/pea category falls into the medium export supply elasticity category. Bagwell and Staiger (2006) find that vegetable products are among the lowest export supply elasticity sectors, with the minerals, plastics, and chemicals sectors having the highest export supply elasticity.²¹

The estimated export supply elasticities reported in Table 1 are somewhat higher than those reported in Broda, Limao, and Weinstein (2008). Since I estimate seasonal/quarterly export supply elasticities, the results are not directly comparable. Examining the elasticities reported in Table 1, there is significant variation across seasons within each of the commodity categories. In general, within each of the

²¹ The Bagwell and Staiger (2006) results are for 16 of the 21 countries which joined the WTO between January 1, 1995 and November of 2005. They find that “Live Animals; Animal Products”, “Vegetable Products”, and “Animal or Vegetable Fats and Oils and Their Cleavage Products; Prepared Edible Fats; Animal or Vegetable Waxes” have the lowest export supply elasticities of the sectors in their analysis. Bagwell and Staiger attribute these results to the regional nature of trade in these products – as a rough check of this hypothesis they find that the number of importer-competing countries is 6 percent lower for animal and vegetable products and the number of export-source countries is 48 percent lower when compared to mineral/chemical/plastic products.

commodity categories, export supply to the US tends to be more elastic in the summer months and less elastic in the winter months. In terms of import demand, there appears to be less variability across seasons within the broccoli/cauliflower, bean/pea, and onion commodity categories. The import demand elasticities in the tomato and pepper categories tend to be higher than in the other categories.

Table 1: Elasticity estimates

Commodity	Season 1		Season 2		Season 3		Season 4	
	η	ω	η	ω	η	ω	η	ω
Broccoli/ Cauliflower	1.92 (0.27)	1.42 (0.10)	3.17 (1.62)	127 (-)	2.35 (0.32)	43.67 (1E-5)	2.77 (0.72)	4.80 (0.01)
Bean/Pea	7.35 (3.07)	0.45 (3.14)	2.17 (0.06)	3.09 (0.01)	5.53 (2.60)	4.09 (0.01)	9.73 (3.84)	3.40 (0.01)
Onion	2.51 (0.06)	22.94 (7E-5)	2.71 (0.32)	4.33 (3E-3)	7.31 (1.92)	127 (-)	4.37 (0.68)	2.93 (6E-3)
Pepper	9.88 (7.81)	2.19 (0.06)	2.24 (0.28)	19.38 (9E-5)	28.76 (36.19)	0.62 (2.10)	26.21 (35.20)	0.13 (1224)
Tomato	132 (-)	1.01 (0.41)	5.19 (1.16)	4.66 (1E-2)	8.35 (4.06)	0.78 (1.90)	30.46 (146.2)	24.95 (4E-3)

* Standard errors in parentheses

4.2 Data

Border Inspection and Detections of Actionable NIS

Daily observations of the outcome of inspections of US fruit and vegetable imports were obtained from the PPQ280 database maintained by the Plant Protection and Quarantine (PPQ) division of APHIS. The PPQ280 database provides a detailed record of daily arrivals of non-propagative (fruit, vegetables, and cut flowers) and propagative (nursery stock) agricultural commodities at US ports of entry.

Commodity name, import volume, import volume inspected, country of origin, port

of entry, and the disposition of imports are recorded. The final disposition record documents which shipments were physically inspected and the outcome of each inspection. The status of imports which enter the US under special programs, such as pre-clearance programs, precautionary treatment programs, or the NARP, is also indicated in the disposition record. See Appendix B for a list of disposition codes used in the PPQ280 database as well as a definition of each disposition code.

For each commodity, total inspected volume, m^H , includes all imports of the commodity that are inspected under the normal surveillance program. The inspected import volume therefore excludes shipments which enter under special import programs such as precautionary treatment programs, pre-clearance programs, and the NARP. The inspected import volume therefore includes shipments entering under the following disposition codes: DEAP, FUAP, FUPQ, IRMR, IRPD, OTAP, OTPQ, RXAP, and RXPQ.

A 'detection' is defined as any record indicating that an actionable pest was detected as well as those records which indicate that action was taken prior to final determination of the actionable status of a detected pest. Total detections therefore include all instances where imports were treated, destroyed, or re-exported due to detection of an actionable or a potentially actionable pest. Shipments entering under the following disposition codes are used to construct the weekly import volume with a detected actionable pest: DEAP, FUAP, FUPQ, OTAP, OTPQ, RXAP, and RXPQ.

Total Import Volume

Total imported volume, m , includes all imports of the commodity admitted into the US for consumption, and therefore excludes those shipments that arrived at US ports of entry that were in-transit to another country or were re-exported for a reason other than detection of an actionable pest (entries with the following disposition codes are excluded from the import volume total: DEPP, DPRP, ENPE, ESRC, IEND, ITNE, RXPC, RXPD, RXPP, RXPQ, RXWP, and TEOC).

Prior to 2007, imports of Canadian grown fruits and vegetables were exempt from border inspection. The PPQ280 database reflects this; a majority of fruit and vegetable imports from Canada are not recorded in the PPQ 280 data. The Fruit and Vegetable Market Report (FVMR) database maintained by the Agricultural Marketing Service (AMS) of the USDA records total production in Canada, rather than imports into the US, and cannot be used to construct import volumes. I construct weekly import volumes of Canadian grown commodities based on monthly trade data (averaged across all days in a month) provided by the Foreign Agricultural Trade of the US (FATUS) database.

As mentioned above, the PPQ280 database records daily outcomes of inspections as well as daily import volumes. This is true with the exception of the ports of Nogales, Arizona and Otay Mesa, California. These two ports record import volumes associated with interceptions of actionable pests on a daily basis but record all other import volumes on the first of each month (for example, import volume for the full month of January is recorded on January 1). The FVMR database is based on daily import volumes reported to them directly by APHIS. I construct weekly import

volumes for Nogales and Otay Mesa as follows. I use the FVMR database to calculate the percentage of imports entering on each day. Next I construct a daily import volume based on the monthly import volume recorded in the PPQ280 database multiplied by the percentage of imports entering each day according to the FVMR database. The daily import volume I construct is then aggregated into a weekly import volume total.

Domestic Production

The FVMR database records daily movement of domestically produced fruit and vegetable commodities net of exports, recorded by volume. I use this data to construct weekly domestic production for domestic consumption y for each of the commodity categories. The lag between harvest and shipment is unknown. Domestic movement data records daily shipments originating from each of the domestic growing regions. Shipments are therefore a function of total harvested volume as well as market conditions such as the volume and price of imported commodities.

Import Tariff

US tariffs on fruit and vegetable imports vary by country of origin and, in the case of the more perishable fruits and vegetables, by season of entry. Tariff rates are obtained from the US ITC online database. Weekly average tariff rates τ for each commodity are computed based on collected duties weighted by import volumes from each country of origin.

Domestic Price

The domestic price is constructed based on the FVMR terminal market database which records daily prices at wholesale produce markets in 15 major US cities. The FVMR database records daily high and low prices for each variety, grade, type of package, and origin (country of origin for imported produce and US growing region for domestic production) at US wholesale markets. The domestic price of imports therefore includes customs, insurance and freight value (CIF) at the port of entry, import charges and costs at the border (including tariffs and user fees), the cost of transporting from the US port of entry to the wholesale market, as well as any marketing margins up to the point of sale in the wholesale market.

I compute national average weekly domestic import prices p for each commodity category as follows. First, an average weekly price is computed for each variety (within a commodity category) and country of origin combination; the average is constructed across variety, grade, and package type. Second, a weighted average domestic price of imports is computed based on the weekly volume of imports by variety and country of origin.

Trade Costs due to Border Inspections

A lower bound on the trade costs due to inspections a is derived from personal interviews conducted with private fumigation companies in New York, Philadelphia, Nogales, Long Beach, and San Diego. These estimates capture the price paid to private fumigation companies to treat commodities with methyl bromide. The estimates therefore do not include costs due to product deterioration or

overtime and other charges for services provided by APHIS staff.²² Based on these interviews, the average fumigation cost ranges from \$0.10/kilogram to \$0.20/kilogram.

Variables and Summary Statistics

The weekly detection rate $h(I, q)$ is constructed for each commodity based on the weekly volume of imports with detections divided by the total weekly volume of inspected imports m^H . The detection rate therefore captures the probability of finding at least one actionable NIS per kilogram of inspected imports. The weekly ratio of inspected import volume to total import volume $\frac{m^H}{m}$ for each commodity is also constructed. The inverse import penetration ratio is computed based on the weekly movement of domestic production for consumption divided by total weekly imports $\frac{y}{m}$. The domestic price and import tariff variables are computed as described above.

Summary statistics for the data used in this analysis are presented in Table 2. Mean detection rates for these commodities are low, ranging from 0.3 percent in the pepper category to 1.7 percent in the onion category. Import volumes are highest in the tomato, pepper, and onion categories. The fraction of imports that are physically inspected varies across commodities. Approximately 90 percent of the total volume

²² Product deterioration due to methyl bromide fumigation varies by commodity. Approximately 84 percent of Red Delicious apples are marketable after fumigation (Calvin, Krissoff, and Foster 2008). Methyl bromide fumigation of citrus can cause fruit losses of up to 60 percent (Lynch 2001). For the six vegetable commodities in this analysis product loss of 15 percent due to fumigation would imply a loss in value of between \$0.11/kilogram for the Carrot category and \$0.65/kilogram for the Legume category.

of broccoli/cauliflower and bean/pea shipments is physically inspected, 50 percent of pepper import volume is inspected, and roughly 20 percent of onion import volume and tomato import volume is physically inspected. There is significant variation in import penetration and prices across these commodity categories. Import penetration and import prices are highest in the pepper, tomato, and bean/pea categories. The tariff rates applied to these vegetable imports are low due to the fact that the majority of these commodities are imported from NAFTA member countries.

Table 2: Weekly summary statistics

	Broccoli/ Cauliflower	Bean/ Pea	Onion	Pepper	Tomato
Detection rate, h	1.3% (1.6)	1.3% (1.7)	1.7% (2.6)	0.3% (0.6)	0.8% (2.6)
Total imports (1,000 kg), m	1,713 (894)	1,323 (641)	4,346 (3,437)	10,600 (3,598)	17,700 (8,844)
Inspected imports (1,000 kg), m^H	1,521 (938)	1,151 (609)	861 (1,114)	5,244 (5,055)	2,951 (2,671)
Inverse import penetration, y/m	7.78 (4.88)	1.95 (1.35)	13.05 (11.17)	0.985 (0.571)	1.99 (1.03)
Domestic import price (\$/kg), p	1.91 (0.39)	4.45 (0.738)	1.27 (0.507)	3.18 (0.490)	2.39 (0.638)
Average tariff rate (\$/kg), τ	0.0008 (0.004)	0.0004 (0.002)	0.004 (0.011)	0.008 (0.008)	0.0004 (0.001)

Note: Standard deviations in parentheses.

5. Results

This chapter presents results for both the reduced form and structural models. The reduced form estimates are presented first, grouped by commodity category. The structural results are presented next. I present results of the terms of trade model with nonlinear instruments as well as linear instruments. The structural model is also estimated assuming no terms of trade motive. The chapter concludes with structural estimation results accounting for seasonal heterogeneity.

5.1 Reduced Form Results

As presented in the chapter outlining the empirical framework, the reduced form specification is based on equation (3.2.1). To control for potential unobserved heterogeneity in the infection rate and/or expected marginal damage across seasons, the reduced form model is estimated both with and without a winter season dummy variable. Both of these models are estimated by ordinary least squares (OLS) and the Tobit procedure in Stata 10.0. Results for each commodity category are presented separately.

5.1.1 Tomato

The reduced form results for the tomato category are presented in Table 3. First, the coefficient on the inverse import penetration ratio is positive and statistically significant at least at the five percent level in all four models. This result is consistent with the comparative static prediction – an increase in the inverse import

penetration ratio increases the detection rate – and robust to inclusion of the winter dummy variable. Since the comparative static prediction relies on an assumption that $\lambda > 1$, these coefficient estimates suggest that the inspection agency places greater weight on the welfare of domestic tomato producers relative to domestic tomato consumers.

Table 3: Reduced Form Tomato Results

	(1) OLS	(2) Tobit	(3) OLS	(4) Tobit
$\frac{y}{m}$	0.010* (0.0045)	0.013* (0.0051)	0.010* (0.0042)	0.012** (0.0045)
p	0.0026 (0.0014)	0.0025 (0.0019)	0.0027 (0.0016)	0.0029 (0.0020)
$\frac{1}{\eta}$	-0.036 (0.023)	-0.038 (0.027)	-0.037 (0.041)	-0.069 (0.056)
$\frac{1}{\omega}$	-0.010* (0.0046)	-0.010* (0.0046)	-0.010* (0.0047)	-0.011* (0.0048)
τ	-1.15 (0.90)	-2.76 (1.63)	-1.13 (0.90)	-2.17 (1.54)
$\frac{m^H}{m}$	-0.030** (0.011)	-0.014 (0.0081)	-0.030** (0.011)	-0.014 (0.0081)
Winter			-0.00031 (0.0062)	-0.0072 (0.0086)
Constant	-0.0042 (0.0067)	-0.017 (0.0094)	-0.0038 (0.0064)	-0.0080 (0.0095)
Sigma:				
Constant		0.025*** (0.0068)		0.025*** (0.0068)
N	156	156	156	156
R ²	0.248		0.248	
Adjusted- R ²	0.217		0.212	
Pseudo- R ²		-0.096		-0.098

Note: Standard errors presented in parentheses. * denotes significance at 5% level; ** denotes significance at 1% level; *** denotes significance at 0.1% level.

The coefficient on domestic price is positive and statistically insignificant in all four models, while the coefficient on the inverse import demand elasticity is negative and also statistically insignificant. The coefficient on the inverse export supply elasticity is negative and statistically significant at the five percent level in all four models. This indicates that the detection rate tends to decrease during seasons when the US has greater market power in the tomato import market. As pointed out Chapter 3, under the assumptions of the model of border inspection, the sign of the coefficient on the inverse export supply elasticity cannot be determined a priori. However, the statistical significance of this coefficient provides evidence that terms of trade considerations do influence inspection intensity.

The coefficient on the tariff rate is negative but is not statistically distinguishable from zero. This provides weak evidence that detections tend to increase when the average tariff rate is lower. The coefficient on the share of imports inspected is negative in all four models and statistically significant at least at the five percent level in the two OLS regressions. A negative coefficient implies that the detection rate decreases as the share of imports inspected increases. According to a strict interpretation of the theoretical model, a negative coefficient implies that the cost of inspection exceeds marginal NIS damage avoided, $k > \delta h_1$. The coefficient on the winter dummy variable is statistically insignificant – evidence that, all else equal, the detection rate associated with tomato imports does not vary by season of entry.

5.1.2 Pepper

Table 4 presents reduced form estimation results for the pepper category.

First, note that the coefficient on the inverse import penetration ratio is positive but statistically insignificant in all four models. These coefficient estimates therefore provide weak evidence that the weight on domestic producer surplus is greater than one.

Table 4: Reduced Form Pepper Results

	(1) OLS	(2) Tobit	(3) OLS	(4) Tobit
$\frac{y}{m}$	0.000086 (0.0013)	0.00021 (0.0013)	0.00011 (0.0014)	0.00023 (0.0013)
p	0.00097 (0.00090)	0.0010 (0.00093)	0.00095 (0.00093)	0.00099 (0.00096)
$\frac{1}{\eta}$	0.0074 (0.0065)	0.0076 (0.0066)	0.0078 (0.0060)	0.0080 (0.0061)
$\frac{1}{\omega}$	0.000037 (0.000081)	0.000043 (0.000095)	0.000015 (0.000072)	0.000021 (0.000096)
τ	-0.029 (0.086)	-0.022 (0.084)	-0.025 (0.093)	-0.018 (0.091)
$\frac{m^H}{m}$	0.0014 (0.0035)	0.0020 (0.0038)	0.0018 (0.0030)	0.0024 (0.0033)
Winter			0.00039 (0.00088)	0.00038 (0.00094)
Constant	-0.0025 (0.0027)	-0.0034 (0.0031)	-0.0029 (0.0021)	-0.0037 (0.0025)
Sigma:				
Constant		0.0057** (0.0021)		0.0057** (0.0021)
N	156	156	156	156
R ²	0.051		0.051	
Adjusted- R ²	0.013		0.006	
Pseudo- R ²		-0.008		-0.008

Note: Standard errors presented in brackets. * denotes significance at 5% level; ** denotes significance at 1% level; *** denotes significance at 0.1% level.

The coefficients on the domestic price, the inverse import demand elasticity, and the export supply elasticity are also positive and statistically insignificant in all four models. Note that the signs on all of these coefficients are robust to inclusion of the winter dummy variable. Estimated coefficients on the share of imports inspected and the tariff rate are statistically insignificant across all four models. Of course, since the comparative static predictions are ambiguous, these results do not contradict the theory. Finally, the estimated coefficient on the winter dummy variables is statistically insignificant in all four models.

5.1.3 Onion

The reduced form results for the onion category are presented in Table 5 below. The coefficient on the inverse import penetration ratio is negative in all four models and statistically significant at the five percent level in the Tobit models (2) and (4). Models (2) and (4) suggest that the weight on domestic producer surplus is less than one in the onion category – evidence that the inspection agency inspects onion imports in a manner that places greater weight on consumer surplus relative to producer surplus.

The coefficient on the domestic price is positive and statistically insignificant in all four models. The inverse import demand elasticity is negative in all four models and statistically significant at the five percent level in model (3). This provides evidence that detections increase in seasons when import demand is more elastic. The coefficient on inverse export supply elasticity is similarly negative, but statistically insignificant in the four models.

Finally, the coefficients on the tariff rate and the share of imports inspected are not statistically significantly different from zero. Once again, insignificant coefficient estimates on these variables do not contradict the model. However, these variables provide very little in the way of explanatory power. The winter dummy variable is also statistically insignificant, providing evidence that detections do not vary systematically by season, holding other variables constant.

Table 5: Reduced Form Onion Results

	(1) OLS	(2) Tobit	(3) OLS	(4) Tobit
$\frac{y}{m}$	-0.00033 (0.00024)	-0.0020* (0.00097)	-0.00035 (0.00024)	-0.0021* (0.00095)
p	0.0030 (0.0057)	0.015 (0.015)	0.0036 (0.0058)	0.018 (0.015)
$\frac{1}{\eta}$	-0.050 (0.031)	-0.17* (0.081)	-0.035 (0.031)	-0.11 (0.085)
$\frac{1}{\omega}$	-0.011 (0.019)	-0.053 (0.053)	-0.0084 (0.020)	-0.042 (0.055)
τ	0.033 (0.19)	0.56 (0.60)	-0.052 (0.17)	0.18 (0.56)
$\frac{m^H}{m}$	-0.014 (0.011)	0.010 (0.033)	-0.0044 (0.011)	0.042 (0.033)
Winter			-0.0080 (0.0065)	-0.030 (0.016)
Constant	0.036** (0.011)	0.030 (0.030)	0.033** (0.011)	0.018 (0.030)
Sigma:				
Constant		0.071*** (0.0091)		0.070*** (0.0092)
N	156	156	156	156
R ²	0.022		0.030	
Adjusted- R ²	-0.018		-0.016	
Pseudo- R ²		-0.236		-0.326

Note: Standard errors presented in brackets. * denotes significance at 5% level; ** denotes significance at 1% level; *** denotes significance at 0.1% level.

5.1.4 Bean/Pea

The reduced form results for the bean/pea commodity category are presented in Table 6. As in the tomato and pepper categories, the coefficient on the inverse import penetration ratio in the bean/pea category is positive across all four models. These coefficient estimates are statistically insignificant in each model, providing weak evidence that the detection rate increases as the inverse import penetration ratio increases.

Table 6: Reduced Form Bean/Pea Results

	(1) OLS	(2) Tobit	(3) OLS	(4) Tobit
$\frac{y}{m}$	0.00087 (0.0014)	0.00084 (0.0015)	0.00080 (0.0014)	0.00078 (0.0015)
p	0.0032 (0.0023)	0.0031 (0.0024)	0.0034 (0.0024)	0.0032 (0.0025)
$\frac{1}{\eta}$	-0.015 (0.012)	-0.020 (0.013)	-0.011 (0.015)	-0.016 (0.016)
$\frac{1}{\omega}$	-0.0020 (0.0017)	-0.0026 (0.0018)	-0.0024 (0.0019)	-0.0029 (0.0020)
τ	-0.62 (0.35)	-0.50 (0.35)	-0.61 (0.35)	-0.50 (0.35)
$\frac{m^H}{m}$	-0.039* (0.018)	-0.039* (0.018)	-0.041* (0.019)	-0.040* (0.019)
Winter			0.0018 (0.0045)	0.0016 (0.0046)
Constant	0.035 (0.018)	0.036 (0.019)	0.035 (0.019)	0.036 (0.019)
Sigma:				
Constant		0.017*** (0.0014)		0.017*** (0.0013)
N	156	156	156	156
R ²	0.106		0.107	
Adjusted- R ²	0.070		0.065	
Pseudo- R ²		-0.023		-0.023

Note: Standard errors presented in brackets. * denotes significance at 5% level; ** denotes significance at 1% level; *** denotes significance at 0.1% level.

The coefficient on the domestic price is positive in all four models, although statistically insignificant. The coefficients on inverse import demand elasticity and inverse export supply elasticity are negative (as they are in the tomato and onion categories) and statistically insignificant in all four models.

Once again, the coefficient on the tariff rate is negative in all four models. To the extent that tariffs vary by season for non-NAFTA imports, these results provide weak evidence that inspection intensity substitutes for the tariff rate, in the sense that the detection rate increases when the average tariff rate is lower.

The coefficient on the share of imports inspected is negative and statistically significant at the five percent level in all models. As in the tomato model, the negative coefficient suggests that the marginal cost of conducting inspections exceeds the marginal avoided NIS damage. As in the previous models, the coefficient on the winter dummy variable is statistically insignificant.

5.1.5 Broccoli/Cauliflower

Table 7 presents reduced form results for the broccoli/cauliflower commodity category. The coefficient on the inverse import penetration ratio is positive in estimations (1) thru (3) and negative in estimation (4). These estimates are statistically insignificant in all four models.

Once again, the coefficient on domestic price is statistically insignificant in all four models. The coefficients on the inverse import demand elasticity and the inverse export supply elasticity are positive and negative, respectively. Further, these coefficient estimates are statistically significant in models (1) and (2) – the models

with the winter dummy variable. These results indicate that detections increase during seasons when import demand is less elastic and export supply is more elastic.

Table 7: Reduced Form Broccoli/Cauliflower Results

	(1) OLS	(2) Tobit	(3) OLS	(4) Tobit
$\frac{y}{m}$	0.00037 (0.00034)	0.00020 (0.00044)	0.000058 (0.00034)	-0.00020 (0.00044)
p	-0.00032 (0.0046)	0.0011 (0.0063)	-0.0016 (0.0044)	-0.00043 (0.0059)
$\frac{1}{\eta}$	0.085* (0.042)	0.12* (0.057)	0.013 (0.060)	0.019 (0.077)
$\frac{1}{\omega}$	-0.040** (0.012)	-0.055** (0.016)	-0.0089 (0.019)	-0.010 (0.026)
τ	-0.39 (0.21)	-0.30 (0.32)	-0.76** (0.29)	-0.81* (0.40)
$\frac{m^H}{m}$	0.026* (0.011)	0.039* (0.016)	0.025* (0.011)	0.037* (0.016)
Winter			-0.015* (0.0059)	-0.021* (0.0082)
Constant	-0.037 (0.023)	-0.067* (0.032)	-0.0015 (0.028)	-0.017 (0.038)
Sigma:				
Constant		0.021*** (0.0019)		0.020*** (0.0018)
N	156	156	156	156
R ²	0.175		0.220	
Adjusted- R ²	0.142		0.183	
Pseudo- R ²		-0.055		-0.075

Note: Standard errors presented in parentheses. * denotes significance at 5% level; ** denotes significance at 1% level; *** denotes significance at 0.1% level.

The coefficient on the tariff rate is negative across all four models, but is statistically significant in models (3) and (4) – the models with the winter dummy variable. There provides weak evidence that the detection rate, and as a consequence inspection intensity, increases when seasonal tariff rates applied to non-NAFTA imports are lower. The coefficient on the share of imports inspected is positive and

statistically significant across all four models. Finally, the winter dummy variable is negative and statistically significant in both models (3) and (4). This is strong evidence that the detection rate is lower in the winter season. The fact that coefficient estimates are sensitive to inclusion of the winter dummy variable may indicate that the seasonal dummy is picking up unobserved heterogeneity other than expected damage across seasons.

Summary

A number of conclusions can be derived from the reduced form estimations. First, with the exception of the onion category, the coefficient on the inverse import penetration ratio tends to be positive. Overall, this provides at least weak evidence that the implied weight on domestic producer surplus is greater than one. The evidence is strongest in the tomato category, followed by the pepper and the bean/pea categories. Given these results, one would expect to find stronger evidence of preferential treatment of domestic tomato, pepper, and bean/pea producers in the structural form estimations. Alternatively, we would expect to find that domestic onion producers receive less preferential treatment than the other commodities in this study.

The coefficient on domestic price is positive but statistically insignificant in all commodity categories, suggesting that variation in prices has little direct explanatory power on detection rates. The coefficient on the inverse import demand elasticity also tends to be statistically insignificant, once again evidence that seasonal variation in import demand elasticity is not an important determinant of detection

rates. The coefficient on the inverse export supply elasticity is negative in all commodity categories with the exception of the pepper category, and statistically significant in the tomato and broccoli/cauliflower categories. This provides weak evidence that inspections are responsive to import market power considerations.

There is weak evidence that the detection rate increases as the average tariff rates applied to imports of tomatoes, peppers, and beans/peas decrease. By extension, this suggests that the inspection agency increases the intensity of inspection of these commodities when the average tariff applied to non-NAFTA imports is lower. In no case is the coefficient on the tariff rate positive and statistically significant.

The winter dummy variable is included in the reduced form estimations as a control for potential unobserved heterogeneity in the infection rate and expected marginal damage. I find that inclusion of seasonal dummy variables does not influence the estimation results in the tomato, pepper, onion, and bean/pea categories. There is some evidence that season of entry is a statistically important determinant of the detection rate in the broccoli/cauliflower models. In addition to the statistical significance of the winter dummy in the broccoli/cauliflower category, its inclusion influences inference on coefficient estimates for the inverse import demand elasticity, the inverse export supply elasticity, and the tariff rate.

5.2 Structural Model Results

In this section the model is estimated in its structural form using the two sets of instruments as outlined in the previous chapter. The model is estimated using the iterated GMM procedure described above. Within each commodity category, I

present four sets of results corresponding to different assumptions regarding trade cost due to inspections a . The assumed trade cost due to inspections are \$0.15/kilogram, \$0.30/kilogram, \$0.60/kilogram, and a 1 percent ad valorem equivalent (1% AVE). The lower bound on trade cost due to inspections of \$0.15/kilogram corresponds to the average cost of fumigating detected contaminated imports. The average detection rates and domestic prices reported in Table 2 are used to compute the upper bound on trade cost due to inspections which corresponds to an ad valorem equivalent of 1 percent for each of the commodity categories.²³ Estimating the model over a range of trade costs provides a method of assessing the sensitivity of the parameter estimates to assumed trade costs due to inspections.

5.2.1 Nonlinear instrumental variables

Results from the structural form model using the set of nonlinear instruments described in Chapter 3 are presented in this section. The four structural parameters k_c , δ_c , q_c , and λ_c are derived from estimates of the parameters in equation (3.3.2). The structural parameter estimates and their associated standard errors are presented in Table 8. There is little evidence against the model specification for four of the five models. The J-statistic reported in Table 8 is distributed as a chi-square with three degrees of freedom.²⁴ For four of the five commodity categories (tomato, pepper,

²³ An ad valorem equivalent (AVE) should be computed on the basis of world price. Since world price is unobserved in this analysis, I express the AVE on the basis of observed domestic prices. The 1%

AVE is derived from the ratio, $a = \frac{\bar{p} \times 0.01}{\bar{h}}$

²⁴ Given the set of instruments used in the analysis, the model has seven moment conditions and four parameters. This leaves three orthogonality restrictions that are used to test the model specification by Hansen's over-identifying restrictions test (Hansen 1982).

bean/pea, and broccoli/cauliflower) the Hansen over-identifying restrictions test implies the model specification and choice of instruments cannot be rejected at the 10 percent level. The onion model specification cannot be rejected at approximately the 5 percent level – thus, the evidence against the onion model is not exceptionally strong.

Weight on Domestic Producer Surplus

The weight on domestic producer surplus is greater than one for all five commodities and significantly greater than one in four of the five commodity categories – evidence suggesting that border inspection protocols are implemented in a manner that protects domestic producers from import competition, independent of expected NIS damage. The estimated weight on domestic producer surplus is greatest in the tomato and pepper categories: estimates range from 1.48 to 1.50 in the tomato category and from 1.58 to 1.59 in the pepper category. The weight on domestic producer surplus ranges from 1.21 to 1.23 in the bean/pea category and the weight on domestic producer surplus in the onion category is estimated to be 1.05. The estimated weight on domestic producer surplus in the broccoli/cauliflower category is 1.14, but this weight cannot be statistically distinguished from 1 at the 5 percent level. Note that for each of the commodity categories the estimated weight on domestic producer surplus is relatively stable across the four sets of results corresponding to different assumed trade costs due to inspections.

Table 8: Parameter estimates with nonlinear instruments

a	\$0.15/kg		\$0.30/kg		\$0.60/kg		1% AVE	
	Parameter	Std Error	Parameter	Std Error	Parameter	Std Error	Parameter	Std Error
Tomato								
$\lambda - 1$	0.496***	0.109	0.484***	0.110	0.479***	0.111	0.475***	0.111
k	0.149	0.078	0.162*	0.080	0.168*	0.082	0.188*	0.093
q	0.022	0.012	0.022	0.012	0.022	0.011	0.022	0.011
δ	6.677	3.514	7.226	3.895	7.458	4.067	7.616	4.188
J-stat	2.306		2.109		2.058		2.043	
p-value	0.511		0.550		0.561		0.564	
Pepper								
$\lambda - 1$	0.585***	0.060	0.585***	0.060	0.584***	0.060	0.578***	0.060
k	0.152***	0.030	0.152***	0.030	0.151***	0.030	0.143***	0.031
q	-0.514	0.691	-0.265	0.359	-0.140	0.193	-0.025	0.050
δ	-0.297	0.394	-0.576	0.768	-1.084	1.464	-5.720	10.616
J-stat	1.927		1.945		1.978		2.444	
p-value	0.588		0.584		0.577		0.485	
Onion								
$\lambda - 1$	0.050**	0.017	0.052**	0.017	0.053**	0.017	0.053**	0.017
k	-0.022	0.158	-0.028	0.165	-0.032	0.172	-0.033	0.174
q	0.005	0.035	0.005	0.029	0.005	0.026	0.005	0.025
δ	-4.117	2.795	-5.172	3.434	-5.975	3.903	-6.173	4.015
J-stat	8.684		8.030		7.557		7.444	
p-value	0.034		0.045		0.056		0.059	
Beans/Peas								
$\lambda - 1$	0.225***	0.044	0.222***	0.043	0.219***	0.041	0.210***	0.026
k	1.020	1.044	1.054	1.118	1.083	1.192	0.938	0.838
q	0.246	0.212	0.137	0.116	0.084	0.071	0.050	0.049
δ	4.163	7.644	7.707	14.383	12.892	24.609	18.650	34.439
J-stat	0.126		0.154		0.223		0.841	
p-value	0.989		0.985		0.974		0.840	
Broccoli/Cauliflower								
$\lambda - 1$	0.136	0.089	0.136	0.089	0.136	0.090	0.135	0.090
k	-0.815	2.038	-0.840	2.167	-0.888	2.408	-1.009	2.967
q	2.779	16.451	1.534	9.033	0.904	5.254	0.514	2.821
δ	-0.215	1.090	-0.390	1.977	-0.666	3.330	-1.182	5.582
J-stat	0.167		0.167		0.167		0.169	
p-value	0.983		0.983		0.983		0.982	

Note: Standard errors computed by delta method; * denotes significance at 5% level; ** denotes significance at 1% level; *** denotes significance at 0.1% level.

Results for the tomato and pepper categories suggest that the extent of the trade distortion due to border inspection can be quite high. For instance, the estimated producer welfare weights imply that the welfare of domestic consumers (and other components of social welfare) is valued at between 63 and 68 percent of producer welfare. The relatively high implicit weight placed on the income of domestic tomato and pepper producers is consistent with anecdotal evidence that these commodities are politically sensitive. Passage of NAFTA was opposed by US vegetable growers due to concerns about increased competition from Mexico. As a part of the NAFTA implementation, tomato and pepper imports were monitored for evidence of import surges thru to January 2009. The estimated welfare weights in the structural analysis are also roughly consistent with reduced form coefficient estimates presented in the previous section. Coefficient estimates on the inverse import penetration ratio were positive for both commodities and were statistically significant in all four of the tomato models.

The implied weight on domestic producer surplus in the bean/pea category is also relatively high, implying that other components of social welfare are valued at approximately 82 percent of producer surplus. This result is also consistent with the reduced form results, which provided weak evidence that the weight on domestic producer surplus is greater than one. Similar to tomato and pepper production, US winter season bean/pea production is geographically concentrated in Florida (Calvin and Barrios 1998). The implied weights on domestic producer surplus in the tomato, pepper, and the bean/pea categories are consistent with the political influence of Florida vegetable growers. Further, import penetration in the tomato, pepper, and

bean/pea categories has increased by more than 150 percent since NAFTA implementation (Huang and Huang 2007). The increase in import penetration is consistent with concerns expressed by US fruit and vegetable growers prior to NAFTA implementation. The high estimates of producer welfare weights in these commodities may reflect a desire to use alternative trade barriers to protect domestic growers from increasing import competition.

The estimated weight on domestic producer surplus in the onion category is relatively low at approximately 1.05. This result contradicts the reduced form estimates, which were negative in all four models and statistically significant in two. This may indicate misspecification of the reduced form onion model. On the other hand, as discussed above, the Hansen over-identifying restrictions test indicates that specification of the onion model is questionable. In both cases, the results suggest that the weight on domestic producer surplus is close to one. Import penetration in the onion category has remained constant since implementation of NAFTA suggesting that imports from Mexico have not had a significant impact on the competitive position of US onion growers. This is consistent with the result that the weight on domestic producer surplus is relatively low in this sector.

Finally, the weight on domestic producer surplus in the broccoli/cauliflower category is 1.14. Although the parameter estimate is greater than one, it is estimated imprecisely, and cannot be statistically distinguished from one.

The weights on domestic producer surplus presented in this analysis are within the range of previous estimates of domestic policy preference weights for agricultural commodities in the US and elsewhere. Oehmke and Yao (1990) find that

US wheat producers receive a welfare weight of 1.43. Ahn and Sumner (2009) report a national average welfare weight on US milk producers of 1.16 relative to domestic consumers. Burton, Love, and Rausser (2004) find that Japanese wheat and rice consumers are valued at about 92 percent of Japanese wheat and rice producers which, in the context of this model, implies a welfare weight on domestic producers of approximately 1.09.

Estimates of producer welfare weights in studies of the US manufacturing sector are somewhat smaller. Goldberg and Maggi (1999) report a weight on social welfare of 98 percent and a weight on campaign contributions of 2 percent. Using an alternative estimation strategy, Eicher and Osang (2002) report a weight on social welfare of 96 percent. Gawande and Bandyopadhyay (2000) find that the US government places equal weight on aggregate welfare and campaign contributions. Although these results provide evidence that the government does not purely maximize social welfare associated with trade in manufactured goods, the extent of the distortion appears to be small relative to the welfare weights on producer surplus as estimated in studies of agricultural policy. These findings suggest that the US agricultural sector is more politically sensitive than the US manufacturing sector.

Expected NIS Damage

Table 9 reports expected NIS damage per kilogram of inspected imports. Estimates of expected NIS damage are highest in the tomato and pepper categories, ranging from \$0.15 to \$0.17 per kilogram. Estimates of expected damage in the onion, bean/pea, and the broccoli/cauliflower categories cannot be distinguished from

zero, suggesting that expected damage due to imports of these commodities is quite low. Estimated expected damage can also be expressed in terms of import values using the average annual prices as reported in Table 2. For every dollar of inspected tomato imports, the inspection agency behaves as if expected damage ranges from \$0.06 to \$0.07. Similarly, for every dollar of inspected pepper imports, the inspection agency behaves as if expected NIS damages are roughly \$0.05. These estimates imply that, for the set of commodities considered in this analysis, the inspection agency behaves as if expected damage ranges from essentially zero to \$0.07 per dollar of imports it inspects.

Table 9: Expected damage with nonlinear instruments, \$/kg imports (δq)

<i>a</i>	\$0.15/kg		\$0.30/kg		\$0.60/kg		1% AVE	
	Parameter	Std Error	Parameter	Std Error	Parameter	Std Error	Parameter	Std Error
Tomato	0.148	0.078	0.160*	0.079	0.165*	0.080	0.168*	0.080
Pepper	0.153***	0.030	0.152***	0.030	0.152***	0.030	0.145***	0.033
Onion	-0.022	0.156	-0.028	0.163	-0.031	0.168	-0.033	0.170
Bean/Pea	1.026	1.049	1.059	1.124	1.088	1.198	0.937	0.840
Broccoli/ Cauliflower	-0.597	0.771	-0.599	0.768	-0.602	0.762	-0.607	0.754

Notes: * denotes significance at 5% level; ** denotes significance at 1% level; *** denotes significance at 0.1% level.

Although not directly comparable, these results can be benchmarked against results from the Peterson and Orden (2008) study of US-Mexico avocado trade. Due to strict US phytosanitary import requirements, US-Mexico avocado trade has been the subject of frequent disputes and a significant amount of research has been devoted to estimating the risks and costs of pest infestation due to avocado imports from

Mexico. Based on this previous research, Peterson and Orden (2008) estimate pest control costs and damages associated with US avocado imports; they consider average and high pest risk situations, as well as variation in the extent of pre-export cleaning. Their estimates are based on avocado-specific pests as well as the expected impact of fruit fly infestations on production of other susceptible agricultural commodities. Assuming low pest infestation risk, they estimate NIS control and damage expenditures to vary from less than \$0.002 per dollar of avocado imports (assuming significant investment in pre-export cleaning) to \$0.03 per dollar of imports (if exporters do not invest in pre-export cleaning). Assuming high pest risk and no pre-export cleaning, the maximum expected damage and control cost is \$0.12 per dollar of avocado imports.

For both the tomato and pepper categories, estimates of expected NIS damage per dollar of imports are below the upper bound presented in Peterson and Orden (2008). The estimated expected damage in the onion, bean/pea, and broccoli/cauliflower categories are essentially zero, suggesting that imports of these commodities are considered to be low risk. To the extent that expected NIS damage is proportional to the total annual production value of the imported commodity, low estimates of expected NIS damage for the bean/pea and broccoli/cauliflower categories is consistent with the fact that the annual domestic production value of these commodities is relatively low. The small estimated damage in the onion category – again not significantly different from zero – is somewhat surprising since annual domestic onion production is relatively high. Estimated NIS damage in the tomato and pepper categories is higher than damage estimates in the other

commodities, consistent with the relatively high annual value of domestic tomato and pepper production. Higher NIS damage estimates in the tomato and pepper categories may also reflect the political profile of domestic producers of these commodities.

5.2.2 Linear instrumental variables

Results from the structural model using linear instrumental variables are presented in this section. The structural parameter estimates and their associated standard errors are presented in Table 10. The J-statistic reported in Table 10 is distributed as a chi-square with three degrees of freedom. When linear instrumental variables are used there is little evidence against the model specification for three of the five commodity categories (tomato, bean/pea, and broccoli/cauliflower). For each of these three models the Hansen over-identifying restrictions test implies the model specification and choice of instruments cannot be rejected at the 10 percent level. There is moderate evidence against the pepper model, which cannot be rejected at the 7 percent level. The onion model cannot be rejected at the 1 percent level – evidence suggesting misspecification of the onion model.

Table 10: Parameter estimates with linear instruments

a	\$0.15/kg		\$0.30/kg		\$0.60/kg		1% AVE	
	Parameter	Std Error	Parameter	Std Error	Parameter	Std Error	Parameter	Std Error
Tomato								
$\lambda - 1$	0.538***	0.070	0.519***	0.073	0.506***	0.076	0.494***	0.079
k	0.109	0.059	0.133	0.069	0.149	0.077	0.179	0.095
q	0.020	0.011	0.020	0.011	0.020	0.010	0.020*	0.010
δ	5.366	2.752	6.435	3.693	7.190	4.424	7.963	5.214
J-stat	2.337		2.158		2.019		1.875	
p-value	0.505		0.540		0.568		0.599	
Pepper								
$\lambda - 1$	0.511***	0.048	0.511***	0.048	0.511***	0.048	0.511***	0.051
k	0.177***	0.025	0.176***	0.024	0.175***	0.023	0.163***	0.016
q	-0.500	0.970	-0.254	0.486	-0.131	0.246	-0.016	0.024
δ	-0.355	0.726	-0.698	1.406	-1.345	2.642	-10.417	15.335
J-stat	6.948		6.952		6.960		7.058	
p-value	0.074		0.073		0.073		0.070	
Onion								
$\lambda - 1$	0.054***	0.010	0.055***	0.010	0.055***	0.010	0.055***	0.010
k	0.036	0.104	0.023	0.109	0.007	0.153	-0.001	0.205
q	0.072	0.091	0.079	0.154	0.102	0.397	0.114	0.581
δ	0.543	1.314	0.371	1.490	0.224	1.599	0.187	1.623
J-stat	13.029		13.014		12.995		12.989	
p-value	0.005		0.005		0.005		0.005	
Beans/Peas								
$\lambda - 1$	0.191***	0.034	0.192***	0.034	0.195***	0.033	0.206***	0.030
k	0.043	0.273	0.016	0.289	-0.029	0.313	-0.204	0.392
q	-0.016	0.114	-0.003	0.059	0.003	0.032	0.008	0.010
δ	-2.662	1.838	-5.071	3.457	-9.205	6.148	-26.230	16.315
J-stat	2.986		2.868		2.710		2.434	
p-value	0.394		0.412		0.438		0.487	
Broccoli/Cauliflower								
$\lambda - 1$	0.089**	0.028	0.089**	0.029	0.088**	0.029	0.087**	0.030
k	-0.193	0.275	-0.197	0.277	-0.206	0.282	-0.226	0.298
q	0.277	0.573	0.155	0.315	0.094	0.185	0.057	0.107
δ	-0.642	0.678	-1.170	1.229	-1.986	2.069	-3.404	3.469
J-stat	0.346		0.343		0.338		0.329	
p-value	0.951		0.952		0.953		0.955	

Note: Standard errors computed by delta method; * denotes significance at 5% level; ** denotes significance at 1% level; *** denotes significance at 0.1% level.

Weight on Domestic Producer Surplus

When linear instruments are used, the weight on domestic producer surplus is significantly greater than one in all five of the commodity categories; again, evidence suggesting that border inspection protocols are implemented in a manner that protects domestic producers from import competition. Once again, the estimated weight on domestic producer surplus is highest in the tomato and pepper categories, ranging from 1.49 to 1.54 in the tomato category and 1.51 in the pepper category. The weight on domestic producer surplus ranges from 1.19 to 1.21 in the bean/pea category and the weights on domestic producer surplus in the broccoli/cauliflower and onion categories are 1.09 and 1.06 respectively. These estimates of the weight on domestic producer surplus are roughly equivalent to estimates using the nonlinear set of instruments, indicating that the estimation results are robust to alternative sets of instruments.

Expected NIS Damage

Estimates of expected NIS damage per kilogram of inspected imports (δq) are presented in Table 11. These estimates indicate that expected damage per kilogram of inspected tomato imports range from \$0.11 to \$0.16. Although insignificant at the 5 percent level, estimates of expected damage in the tomato category are statistically significant at least at the 8 percent level. Expected damage per kilogram of inspected pepper imports are estimated with a higher degree of precision and range from \$0.17 to \$0.18, slightly higher than estimates obtained using

nonlinear instruments. These estimates suggest that the inspection agency behaves as if expected damage per dollar of inspected pepper imports is approximately \$0.05. For the remainder of the commodity categories, expected damage per kilogram of imports cannot be distinguished from zero. These results are consistent with results obtained using nonlinear instruments.

Table 11: Expected damage with linear instruments, \$/kg imports (δq)

<i>a</i>	\$0.15/kg		\$0.30/kg		\$0.60/kg		1% AVE	
	Parameter	Std Error	Parameter	Std Error	Parameter	Std Error	Parameter	Std Error
Tomato	0.109	0.059	0.131	0.068	0.146	0.075	0.161	0.083
Pepper	0.177***	0.024	0.177***	0.024	0.176***	0.022	0.165***	0.017
Onion	0.039	0.103	0.029	0.104	0.023	0.104	0.021	0.104
Bean/Pea	0.044	0.275	0.016	0.290	-0.029	0.314	-0.204	0.392
Broccoli/ Cauliflower	-0.178	0.244	-0.181	0.242	-0.186	0.241	-0.195	0.238

Note: * denotes significance at 5% level; ** denotes significance at 1% level; *** denotes significance at 0.1% level.

5.2.3 Terms of Trade

In this section I evaluate the influence of terms of trade on inspection intensity. As described in Chapter 3, the no terms of trade model is estimated by imposing an assumption that $\omega = \infty$. The no terms of trade model is then compared to the terms of trade model (results presented in Table 8) on the basis of tests of the over-identifying restrictions imposed by the two models. As an example, if the over-identifying restrictions test presents strong evidence against the no terms of trade model and only weak evidence against the terms of trade model, this is interpreted as

evidence that terms of trade influence border inspections. Results of the no terms of trade estimation are presented in Table 12.

Table 12: Parameter estimates assuming no terms of trade

a	\$0.15/kg		\$0.30/kg		\$0.60/kg		1% AVE	
	Parameter	Std Error	Parameter	Std Error	Parameter	Std Error	Parameter	Std Error
Tomato								
$\lambda - 1$	0.625***	0.074	0.627***	0.074	0.627***	0.074	0.628***	0.074
k	-0.010	0.053	-0.010	0.053	-0.010	0.054	-0.013	0.062
q	-0.003	0.018	-0.003	0.017	-0.003	0.017	-0.003	0.017
δ	3.374	3.194	3.440	3.268	3.474	3.307	3.505	3.337
J-stat	3.639		3.632		3.628		3.626	
p-value	0.303		0.304		0.305		0.305	
Pepper								
$\lambda - 1$	1.052	1.103	0.917	1.144	0.691	1.157	-1.287	1.321
k	0.180	0.238	0.140	0.371	1.714	966.109	-0.004	0.026
q	-0.092	0.321	-0.082	0.564	3.046	1852.172	0.000	0.002
δ	-2.316	9.935	-2.245	17.581	0.045	27.593	88.793	56.840
J-stat	6.534		7.109		8.148		8.657	
p-value	0.088		0.069		0.043		0.034	
Onion								
$\lambda - 1$	0.012*	0.006	0.012*	0.006	0.012*	0.006	0.012*	0.006
k	-0.038	0.430	-0.061	0.612	-0.104	0.983	-0.125	1.170
q	0.043	0.449	0.039	0.370	0.037	0.332	0.037	0.325
δ	-0.283	1.439	-0.342	1.592	-0.380	1.682	-0.388	1.701
J-stat	2.012		1.998		1.990		1.988	
p-value	0.570		0.573		0.574		0.575	
Beans/Peas								
$\lambda - 1$	-0.082	0.058	-0.080	0.058	-0.077	0.059	-0.069	0.066
k	-0.395	0.674	-0.417	0.760	-0.467	0.943	-1.034	2.892
q	0.957	2.538	0.536	1.438	0.329	0.901	0.170	0.509
δ	-0.176	0.440	-0.308	0.764	-0.488	1.203	-0.885	2.254
J-stat	0.022		0.030		0.044		0.099	
p-value	0.999		0.999		0.998		0.992	
Broccoli/Cauliflower								
$\lambda - 1$	0.090*	0.042	0.091*	0.043	0.092*	0.044	0.094*	0.046
k	-0.490	0.367	-0.478	0.362	-0.456	0.352	-0.394	0.319
q	-0.335*	0.169	-0.192	0.098	-0.120	0.062	-0.077	0.041
δ	1.664	0.855	2.898	1.501	4.604	2.409	7.034	3.736
J-stat	0.733		0.724		0.718		0.722	
p-value	0.865		0.868		0.869		0.868	

Note: Standard errors computed by delta method; * denotes significance at 5% level; ** denotes significance at 1% level; *** denotes significance at 0.1% level.

The terms of trade version of the tomato model cannot be rejected at least at the 50 percent level, whereas the no terms of trade version cannot be rejected at approximately the 30 percent level. Therefore, although both versions of the tomato model cannot be rejected at conventional significance levels, the evidence supporting specification of the terms of trade model is stronger than the evidence supporting the no terms of trade model. The estimation results also indicate that the estimated weight on domestic producer surplus increases from approximately 1.48 in the terms of trade model to 1.63 in the no terms of trade tomato model.

As mentioned above, specification of the no terms of trade version of the pepper model cannot be rejected only at the 10 percent level. On the other hand, specification of the terms of trade model cannot be rejected at least at the 50 percent level. These statistical specification tests therefore support the terms of trade version of the model. Also, when the terms of trade assumption is dropped, the point estimates of the weight on pepper producer surplus vary widely depending on the assumed trade cost due to inspections and are estimated with very little precision. Despite large estimates of the weight on producer welfare (both positive and negative), none of the estimates can be statistically distinguished from one. In contrast, estimates of the weight on domestic producer surplus in the terms of trade model are precisely estimated and stable across different assumed trade costs. Overall, the statistical specification test and the precision of the parameter estimates provide strong evidence in favor of the terms of trade version of the pepper model.

In contrast to the pepper model, specification of the onion model improves in the no terms of trade version. Specifically, the terms of trade version of the model

cannot be rejected at least at the 6 percent level, whereas the no terms of trade version of the onion model cannot be rejected at the 57 percent level. With respect to the weight on domestic producer surplus, the parameter estimate falls from 1.05 in the terms of trade version of the model to 1.01 in the no terms of trade version of the model. Although both estimates of the producer welfare weight are relatively low, they are both statistically distinguishable from one. There is therefore strong evidence supporting the no terms of trade version of the onion model as well as evidence (in both versions of the model) that the welfare weight on domestic onion producers is very close to one.

There is strong evidence supporting both specifications of the bean/pea model. In fact, distinguishing the two versions of the bean/pea model on the basis of model specification tests is difficult. In the terms of trade version of the model, the weight on domestic producer surplus was estimated at approximately 1.22 and significantly greater than one. In the no terms of trade version, the estimated weight is approximately 0.92 but cannot be statistically distinguished from one. Although imprecisely estimated, the remaining parameter estimates are the correct sign and of plausible magnitudes in the terms of trade version of the model. In the no terms of trade version of the model, estimates of the cost of inspection effort and expected damage are negative and estimates of the expected infection rate are quite high. Therefore, although the two versions of the bean/pea model cannot be distinguished on the basis of statistical specification tests, the behavioral implications of the parameter estimates support the terms of trade version of the model.

Similar to the tomato and the bean/pea models, the broccoli/cauliflower model cannot be rejected at conventional significance levels in both the terms of trade and the no terms of trade versions of the model. As in the tomato model the specification test does support the terms of trade assumption. The terms of trade model cannot be rejected at the 98 percent level, whereas the non terms of trade model cannot be rejected at the 87 percent level. Estimates of the weight on domestic producer surplus are significantly greater than one in both models and stable across all assumed trade costs due to inspections. Note that there is little difference in the estimated weight on producer welfare: in the terms of trade model the estimated weight is 1.14 (not statistically distinguishable from one) and in the no terms of trade model the estimated weight is 1.09. Overall, there is weak evidence in support of the terms of trade model and the estimated weight on domestic producer is robust to the terms of trade assumption (although more precisely estimated in the no terms of trade model).

5.2.4 Seasonal Heterogeneity

In this section I address potential heterogeneity in the expected infection rate and marginal damages within a commodity category across seasons. Expected damage may vary across seasons for a number of reasons. If the mix of exporters varies through the course of a year, expected infection rates may differ due to variation in background pest infestation levels or the stringency of phytosanitary controls across exporters.²⁵ Also, depending on the port of entry and final destination of imported goods, expected NIS damage may vary across seasons due to increased

²⁵ Costello et al. (2007) demonstrate that risk of aquatic invasions into the San Francisco Bay varies by regional trading partners.

pest establishment potential in summer months as compared to winter months, particularly in northern US states.

Despite these concerns, seasonal heterogeneity in expected infection rates and NIS damage is expected to be low. Expected damage is a function of the type and the potential diversity of NIS arrivals as well as the likelihood of establishment after introduction. APHIS determines establishment risk based on the presence and susceptibility of hosts as well as the presence and duration of climatic conditions suitable for establishment (Sequeira, Millar, and Bartels 2001). As an example, one pest of current regulatory concern is the Mexfly which is distributed throughout Mexico, Central America, and South America. Due to year-round presence of susceptible hosts and the absence of winter conditions that otherwise prevent establishment, the southern US is considered the only high-risk establishment region in the US (Sequeira, Millar, and Bartels 2001).²⁶

As is shown in Table 13, over 95 percent of bean/pea, pepper, and tomato inspected imports enter through southern ports and over 90 percent of broccoli/cauliflower and onion inspected imports enter through southern ports. Since susceptible hosts are present in the southern states year-round, it is assumed that heterogeneity in expected damages across seasons is low for the set of commodities in this analysis.

²⁶ Similarly, a separate analysis of the establishment potential of fruit fly finds that cold weather exclusion areas prevent establishment in most of the US, with the exception of the Southern states (Margosian et al. ND).

Table 13: Inspected import shares by port at state level

State		Broccoli/ Cauliflower	Bean/Pea	Onion	Pepper	Tomato
Arizona	s	0.11	0.32	0.09	0.48	0.57
California	s	0.27	0.15	0.36	0.17	0.27
Colorado					0.00	0.00
Delaware		0.01	0.00	0.00		
Florida	s	0.03	0.46	0.09	0.01	0.00
Georgia	s	0.00	0.00	0.03	0.00	0.00
Idaho		0.00	0.00	0.00		
Illinois		0.00	0.00	0.00	0.01	0.00
Indiana		0.00	0.00	0.00		
Kentucky				0.00		
Louisiana	s	0.00				
Massachusetts		0.00	0.00	0.00	0.01	0.00
Maryland			0.00	0.00	0.00	0.00
Michigan		0.00		0.00	0.00	0.01
Minnesota					0.00	
Mississippi	s				0.00	
Montana		0.00	0.00		0.00	0.00
North Carolina			0.00		0.00	
North Dakota		0.00		0.00	0.00	0.00
New Jersey		0.00	0.00	0.04	0.02	0.00
New Mexico	s			0.00	0.13	0.00
Nevada				0.00		
New York		0.05	0.00	0.04	0.01	0.00
Ohio					0.00	0.00
Oregon					0.00	0.00
Pennsylvania			0.00	0.02	0.00	0.00
Rhode Island		0.00		0.00		
South Carolina	s			0.01		
Tennessee			0.00		0.00	
Texas	s	0.53	0.06	0.32	0.16	0.14
Virginia		0.00	0.00	0.00	0.00	0.00
Vermont		0.00			0.00	0.00
Washington		0.00	0.00	0.00	0.00	0.00
Southern port share		0.93	0.99	0.90	0.96	0.99

* Note: 's' denotes southern state

The monthly share of inspected imports, broken down by geographic region of origin, is presented in Table 14. The inspected import mix stays relatively constant throughout the year for the tomato, pepper, and broccoli/cauliflower categories. The inspected import mix for the bean/pea category varies through the course of the year primarily due to an increase in inspected imports from South America for the months

July through November. Inspected onion import shares vary throughout the year, divided among Mexico, South America, Central America, and an aggregate of other regions.

Table 14: Inspected import shares by geographic region of origin and month

Commodity	Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Broccoli/ Cauliflower	C. America	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.03	0.03	0.03	0.01
	Mexico	0.99	0.99	0.99	0.99	0.98	0.99	0.97	0.96	0.97	0.96	0.95	0.98
	Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
	S. America	0.00	0.00	0.00	0.00	0.00		0.00	0.01	0.01	0.01	0.01	0.01
Bean/Pea	C. America	0.41	0.44	0.42	0.50	0.69	0.61	0.64	0.66	0.53	0.27	0.30	0.32
	Mexico	0.57	0.55	0.57	0.48	0.27	0.32	0.19	0.14	0.12	0.24	0.50	0.66
	Other	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.04	0.03	0.02	0.02	0.01
	S. America	0.00	0.00	0.00	0.00	0.01	0.04	0.14	0.16	0.31	0.47	0.18	0.01
Onion	C. America	0.04	0.09	0.12	0.08	0.04	0.04	0.05	0.04	0.04	0.04	0.06	0.05
	Mexico	0.14	0.25	0.43	0.35	0.57	0.79	0.68	0.37	0.21	0.14	0.14	0.13
	Other	0.17	0.21	0.26	0.24	0.27	0.15	0.25	0.48	0.22	0.19	0.24	0.16
	S. America	0.65	0.45	0.18	0.33	0.12	0.02	0.02	0.11	0.52	0.62	0.57	0.66
Pepper	C. America	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
	Mexico	0.89	0.90	0.92	0.93	0.84	0.84	0.81	0.89	0.91	0.93	0.89	0.91
	Other	0.10	0.08	0.07	0.07	0.16	0.16	0.19	0.11	0.08	0.07	0.11	0.09
	S. America	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tomato	C. America			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mexico	0.86	0.93	0.90	0.86	0.90	0.98	0.97	0.91	0.87	0.95	0.95	0.95
	Other	0.14	0.07	0.10	0.14	0.10	0.02	0.03	0.09	0.13	0.05	0.05	0.05
	S. America	0.00	0.00									0.00	0.00

In order to allow for seasonality in expected NIS damage and expected infection rates the terms of trade model is estimated allowing the parameters $\frac{k_c}{q_c}$, δ_c , and $\delta_c q_c$ to vary across the summer and winter seasons. Additional moment conditions are constructed by interacting the nonlinear instrumental variables with seasonal dummy variables. I test for the presence of seasonality based on a null hypothesis that the parameter estimates of expected NIS damage per kilogram of inspected imports are equal across the summer and winter seasons $\delta q_{\text{Summer}} = \delta q_{\text{Winter}}$. Outcomes of these hypotheses tests are presented in Table 15.²⁷

Table 15: Tests of equality of seasonal parameters $H_0 : \delta q_{\text{Summer}} = \delta q_{\text{Winter}}$

<i>a</i>	\$0.15/kg		\$0.30/kg		\$0.60/kg		1% AVE	
	Test Statistic	p-value	Test Statistic	p-value	Test Statistic	p-value	Test Statistic	p-value
Tomato	1.282	0.258	1.122	0.290	1.101	0.294	1.039	0.308
Pepper	7.983	0.005	7.724	0.005	7.261	0.007	3.606	0.058
Onion	17.125	0.000	17.323	0.000	17.181	0.000	17.104	0.000
Bean/pea	4.257	0.039	3.808	0.051	3.118	0.077	1.121	0.290
Broccoli/ Cauliflower	0.659	0.417	0.747	0.387	0.911	0.340	18.331	0.000

There is strong evidence suggesting that expected NIS damage varies across season for the pepper and onion categories. In the pepper category, the hypothesis that expected NIS damage varies across season can be rejected at least at the 10

²⁷ The test statistics are distributed as $\chi^2(1)$.

percent level across all assumed trade costs. In the onion category, there is strong evidence suggesting seasonal heterogeneity no matter what assumption is made about trade costs due to inspections. There is little evidence to suggest that expected NIS damage varies across season in the tomato category. This result holds irrespective of assumed trade costs due to inspections. There is weak evidence that expected damage varies across season in the broccoli/cauliflower categories and somewhat stronger evidence of seasonality in the bean/pea category.

In Table 16 I present parameter estimates for the weight on domestic producer surplus and expected NIS damage per kilogram of inspected imports for the summer and winter seasons for each commodity category. Note that the over-identifying restriction tests present little evidence against the seasonal heterogeneity specifications of the tomato, pepper, onion, and bean/pea models and the evidence against the seasonal heterogeneity specification the broccoli/cauliflower model is moderate.²⁸

First, note that the estimated weights on domestic producer surplus in the tomato and pepper categories reported in Table 16 – between 1.45 and 1.53 in the tomato category and between 1.61 and 1.63 in the pepper category – are roughly the same as the estimates reported in Table 8. The estimated weight on domestic producer surplus in the onion category is estimated to range from 1.04 to 1.05 in the estimations allowing for seasonality. This compares to an estimate of approximately 1.05 with no seasonal heterogeneity.

²⁸ The model allowing for seasonal heterogeneity has fourteen moment conditions and seven parameters, leaving seven orthogonality restrictions that are used to test the model specification.

Table 16: Parameter estimates allowing for seasonal heterogeneity

<i>a</i>	\$0.15/kg		\$0.30/kg		\$0.60/kg		1% AVE	
	Parameter	Std Error	Parameter	Std Error	Parameter	Std Error	Parameter	Std Error
Tomato								
$\lambda - 1$	0.532*	0.234	0.469*	0.222	0.459*	0.222	0.445*	0.222
δq_{Summer}	0.061	0.177	0.107	0.167	0.118	0.168	0.131	0.168
δq_{Winter}	0.164	0.112	0.199	0.108	0.209	0.109	0.220	0.111
J-stat	7.252		4.246		3.991		3.738	
p-value	0.403		0.751		0.781		0.809	
Pepper								
$\lambda - 1$	0.613***	0.055	0.613***	0.055	0.614***	0.055	0.625***	0.059
δq_{Summer}	0.025	0.056	0.026	0.057	0.027	0.058	0.041	0.068
δq_{Winter}	0.182***	0.011	0.182***	0.011	0.182***	0.011	0.173***	0.012
J-stat	4.034		4.029		4.021		3.823	
p-value	0.776		0.776		0.777		0.800	
Onion								
$\lambda - 1$	0.044***	0.006	0.044***	0.006	0.045***	0.006	0.045***	0.006
δq_{Summer}	0.058	0.078	0.054	0.078	0.052	0.078	0.052	0.078
δq_{Winter}	0.363***	0.041	0.358***	0.040	0.354***	0.040	0.353***	0.040
J-stat	11.148		10.981		10.913		10.906	
p-value	0.132		0.139		0.142		0.143	
Bean/pea								
$\lambda - 1$	0.030	0.032	0.030	0.032	0.031	0.032	0.034	0.033
δq_{Summer}	-0.220	0.290	-0.197	0.297	-0.157	0.310	0.030	0.369
δq_{Winter}	0.428***	0.035	0.429***	0.035	0.430***	0.035	0.441***	0.033
J-stat	5.125		5.111		5.101		5.320	
p-value	0.645		0.646		0.648		0.621	
Broccoli/Cauliflower								
$\lambda - 1$	0.020**	0.008	0.021**	0.008	0.021**	0.008	0.021**	0.008
δq_{Summer}	0.495***	0.031	0.494***	0.030	0.493***	0.029	0.503***	0.031
δq_{Winter}	0.456***	0.046	0.451***	0.047	0.444***	0.047	0.214***	0.058
J-stat	14.234		14.251		14.259		10.595	
p-value	0.047		0.047		0.047		0.157	

Note: Standard errors computed by delta method; * denotes significance at 5% level; ** denotes significance at 1% level; *** denotes significance at 0.1% level.

When seasonal heterogeneity is allowed, the estimated producer welfare weight in the bean/pea category is approximately 1.03 and cannot be statistically distinguished from one. This contrasts with the results of the specification that does

not allow for seasonal heterogeneity; as reported in Table 8 the estimated weight on domestic producer surplus is approximately 1.22. The weight on domestic producer surplus in the broccoli/cauliflower model is estimated at 1.02 when seasonal heterogeneity is allowed. Although small – compared to the estimated weight of 1.14 with no seasonal –heterogeneity – the estimated weight of 1.02 is statistically greater than one. Once again, note that there is moderate evidence against the broccoli/cauliflower model when seasonality is allowed.

Taking seasonal heterogeneity into account, estimated NIS damage due to pepper imports cannot be distinguished from zero in the summer, whereas in the winter, estimated damage is \$0.05 per dollar of inspected pepper imports. Expected damage due to inspected bean/pea imports cannot be distinguished from zero in the summer and is approximately \$0.10 per dollar in the winter season. The increase in expected NIS damage in the winter months corresponds to an increase in the share of inspected imports arriving from Mexico during the same period (see Table 14). This may imply that expected damages due to import of winter season peppers and beans/peas from Mexico are higher. Higher expected damage implied by inspection intensity may also reflect more intensive screening of winter season imports due to increased concern about competition from winter season imports.

Expected damage due to onion imports cannot be distinguished from zero in the summer and is estimated at approximately \$0.28 per dollar of imports in the winter season. Expected damage associated with broccoli/cauliflower imports are roughly equivalent across months. Assuming trade cost due to inspections are less than \$0.30 per kilogram, expected damages are estimated at approximately \$0.26 per

dollar of inspected imports in both the summer and winter. These estimates diverge when assumed trade cost due to inspections are greater than \$0.60 per kilogram; in this case expected damage remains at approximately \$0.26 per dollar of imports in the summer and decreases to approximately \$0.11 per dollar of imports in the winter. Recall that the reduced form broccoli/cauliflower model indicated that the winter dummy variable was negative and statistically significant. This is consistent with lower structural estimates of expected damage in the winter months.

5.3 Concluding Remarks

This chapter presents estimation results for both reduced form and structural models of border inspection. The terms of trade structural model is estimated using nonlinear instruments and the robustness of those results is confirmed by an estimation based on linear instruments. In addition to the terms of trade model, two additional structural models are estimated corresponding to alternative behavioral assumptions. First, in order to assess the impact of terms of trade on border inspections, the model is estimated with no terms of trade. Second, due to potential seasonal heterogeneity in the expected infection rate and marginal damage, the terms of trade model is estimated allowing expected damages to vary by season.

I find evidence that border inspection of tomato imports is implemented in a trade distorting manner, both with respect to the weight on domestic producer surplus and terms of trade. I also find little evidence of seasonal heterogeneity in expected damage due to tomato imports. The terms of trade model with no seasonal heterogeneity is therefore the preferred specification for tomatoes. The implicit

weight on domestic producer surplus is significantly greater than one and implies a large premium is placed on domestic producer welfare relative to consumer welfare. The estimated welfare weight on domestic tomato producers is approximately 1.48, implying that domestic consumer welfare is valued at 68 percent of domestic producer welfare. In addition to shifting surplus from consumers to producers, I also find that terms trade considerations influence border inspection of tomatoes. This suggests that the inspection agency is able to offset the effect of inspections on domestic price by passing some of the cost of inspection through to the world price. Finally, I find that the inspection agency behaves as if expected damage ranges from \$0.06 to \$0.07 per dollar of inspected imports, independent of the season of entry.

Since there is strong evidence against the no terms of trade model and evidence indicating seasonal heterogeneity, inspection of pepper imports is best characterized by the terms of trade model with seasonal heterogeneity. In this model, the estimated welfare weight on domestic pepper producers is quite high, ranging from 1.61 to 1.63. Similar to domestic tomato producers, US pepper producers are politically influential and, as mentioned earlier, have demonstrated an ability to influence trade policy in the past. This is consistent with the high estimated welfare weights for these two commodities. Once again, there is strong evidence against the no terms of trade version of the model, indicating that terms of trade factors do influence border inspection of pepper imports. With respect to damages, I find that the inspection agency behaves as if expected damage is essentially zero in the summer and increases to \$0.06 per dollar of imports in the winter.

In contrast to the previous two commodities, there is strong evidence against the terms of trade model for onions. There is also strong evidence of seasonal heterogeneity in expected damages. Further, the estimated welfare weight on domestic onion producers is low in all versions of the model, never exceeding 1.05. Overall, these results suggest that inspection of onion imports is not conducted in a trade distorting manner; there is evidence of a small implicit transfer from consumers to producers and terms of trade motives do not appear to influence inspections. There is significant heterogeneity in expected damage across seasons. Similar to peppers, I find that the inspection agency behaves as if expected damage is zero in the summer and increases to \$0.29 per dollar of imports in the winter. The difference in expected damage in the summer versus the winter months roughly corresponds to a shift in the source of imports from Mexico in the summer to Central American countries in the winter. These results imply that onion imports from Central America are considered to be potentially more damaging than onion imports from Mexico.

There is little evidence against the terms of trade model with no seasonality for the bean/pea category. First, dropping terms of trade motives from the model does little to improve the specification. Second, there is only weak evidence that damages vary by season. In the terms of trade model with no seasonal heterogeneity, the weight on domestic producer surplus is significantly greater than one and is estimated to range from 1.21 to 1.23. These results imply that border inspection of bean/pea imports is conducted in a trade distorting manner, both respect to protectionist and terms of trade motives. Assuming no seasonal heterogeneity, I find that the inspection agency behaves as if expected damage is very close to zero.

Finally, the terms of trade model with no seasonal heterogeneity best characterizes inspection of broccoli/cauliflower imports. Although the estimate of the weight on domestic producer surplus is approximately 1.14, it is imprecisely estimated and cannot be statistically distinguished from one. Therefore, aside from evidence that terms of trade influence inspections, there is little evidence that border inspection of broccoli/cauliflower imports is conducted in order to transfer surplus from consumers to producers. As with bean/pea imports, I find that the inspection agency considers broccoli/cauliflower imports to be very low risk – estimate of expected damage cannot be distinguished from zero.

6. Conclusion

Uncertain potential damages due to foreign pest and disease introductions, combined with a lack of transparency in enforcement, contribute to a perception that government agencies use biosecurity import restrictions as disguised barriers to trade. Recognizing this, international trade agreements prohibit the use of border inspections as arbitrary or unjustified barriers to trade. However, despite the perception that enforcement of biosecurity import restriction may be used as a disguised trade barrier, there is little systematic empirical analysis distinguishing genuine attempts to protect against foreign pest and disease introductions from attempts to distort trade.

In this dissertation I examine the extent to which border inspections for NIS are used as a distortionary trade barrier. I begin by developing a theoretical model of optimal border inspection intensity by a government agency with a mandate to screen imports to prevent unintentional NIS introductions. Optimal inspection intensity trades off avoided NIS damage with the impact of border inspections on prices, and as a consequence on domestic producer and consumer surplus. I use the theoretical model to specify an econometric model of US agricultural border inspections for NIS. The econometric model is used to test the degree to which border inspections are used as a distortionary barrier to trade – both to protect domestic producers from import competition as well as to influence terms of trade – and to determine the levels of expected damage implied by the stringency of border inspections.

The theoretical model builds on the existing literature in a number of ways. I incorporate a politically influential domestic production sector and relax the small country assumption imposed by prior border inspection models. I assume detected imports are treated rather than destroyed – an assumption that is consistent with US agricultural border inspections. I also introduce a more general specification of the detection rate as a function of inspection intensity and the expected infection rate. Two cases are considered in the theoretical analysis. First, I consider the case where the optimal tariff and optimal inspection intensity are set jointly. Second, I consider the case where the tariff is predetermined as a result of constraints imposed by trade agreements.

When the government has the option of setting an optimal tariff, I show that inspection intensity is independent of the weight on domestic producer surplus. In this case the government prefers to use import tariffs to achieve its distributional objectives. When both instruments are set jointly, I show that an increase in the marginal cost due to border inspection, including both the cost of conducting inspections as well as trade costs due to inspections, will decrease optimal inspection intensity; an increase in marginal expected damage due to admitted NIS increases optimal inspection intensity; and an increase in the cost of treating detected imports, which reduces the marginal net benefit of inspections, decreases optimal inspection intensity. Finally, when the expected infection rate increases, the inspection agency may prefer to inspect imports more or less intensively. Prior models of border inspection also find an ambiguous relationship between inspection intensity and the infection rate. However, in these models this result is due to the assumption that

detected imports are destroyed. When detected imports are treated, I show that the ambiguous relationship between inspection intensity and the infection rate is due to the more general specification of the detection rate I introduce.

Empirically, the tariff is likely constrained by trade agreements. For example, the US has entered into a number of free trade agreements with countries that export fruit and vegetables to the US. These include multilateral trade agreements, such as NAFTA, the Dominican Republic-Central America-United States Free Trade Agreement, the United States-Caribbean Basin Trade Agreement, and a number of bilateral agreements with countries such as Australia, Chile, and Peru. The tariff applied to fresh fruit and vegetable imports from these trading partners is zero and therefore too low from a political economy, terms of trade, and NIS perspective. In the case where the predetermined tariff is set lower than optimal I show that the inspection agency prefers to inspect imports more intensively relative to the first best level of inspection intensity.

When the tariff is predetermined, an increase in the weight on domestic producer surplus increases optimal inspection intensity. Optimal inspection intensity also increases in response to an increase in expected damage. This implies that the inspection agency prefers to inspect imports more intensively in response to both an increase in the weight on domestic producer surplus and an increase in expected damage. The response of optimal inspection intensity to the cost of treating detected imports is less straightforward. When the tariff is predetermined, an increase in the cost of treating detected imports no longer strictly reduces the marginal net benefit of inspections. Rather, an increase in the cost of treating detected imports increases the

responsiveness of domestic price to inspection intensity. As a consequence, border inspections become a more effective instrument in terms of transferring surplus from consumers to producers, and an increase in the cost of treatment may lead to an increase in optimal border inspection intensity. This is more likely to occur if the predetermined tariff is lower than the optimal tariff. As was the case when the tariff was set optimally, if the tariff is predetermined, inspection intensity may increase or decrease due to an increase in the expected infection rate.

The empirical component of this dissertation examines the extent to which US agricultural border inspections for NIS are conducted in a trade distorting manner. I use the theoretical model to specify reduced form and structural models of optimal border inspection. The models are estimated using a dataset that documents the outcome of US agricultural border inspections for NIS, combined with publicly available data on weekly import volumes, domestic production volumes, the domestic prices of imports, and import tariffs. Separate models are estimated for five vegetable commodities imported into the US, including tomatoes, peppers, onions, beans/peas, and broccoli/cauliflower.

The primary goal of the empirical analysis is to quantify the implied weight the inspection agency places on domestic producer welfare relative to other components of social welfare. The welfare weight on domestic tomato and pepper producers is of particular interest due to anecdotal evidence suggesting that these are politically powerful producer groups. US fruit and vegetable growers opposed NAFTA due to a concern that the removal of seasonal import tariffs would force them to compete with increased fruit and vegetable imports from Mexico. Fruit and

vegetable growers pushed for longer transition periods and protection from import surges. As a part of NAFTA implementation, US tomato and pepper imports from Mexico were monitored for evidence of import surges through to January 2009.

I find evidence suggesting that border inspection protocols are conducted in a trade distorting manner. The reduced form analysis suggests that the weight on domestic producer surplus is greater than one and the estimated weight on domestic producer surplus in the structural analysis ranges from 1 to 1.63. The structural results imply that the welfare of domestic consumers is valued from 61 to 100 percent of domestic producer welfare. The implied weights on domestic producer surplus are highest in the tomato and pepper categories, estimated to range from 1.48 to 1.5 for tomatoes and from 1.61 to 1.63 for peppers. The estimated welfare weight is approximately 1.22 on bean/pea growers, less than 1.05 on domestic onion growers, and the estimated weight on broccoli/cauliflower growers cannot be distinguished from one. Overall, the results of the structural model suggest that the weight on domestic producers is never less than one, is greater than one in the majority of commodities in this analysis, and in some cases is quite large.

I also find evidence that terms of trade motives influence border inspection of a number of the commodities in the analysis. The influence of terms of trade is tested based on a comparison of the over-identifying assumptions imposed by two competing models of border inspection: the terms of trade and the no terms trade versions of the model. Based on this comparison, I find evidence in favor of the terms of trade version of the tomato and pepper models, implying terms of trade considerations influence tomato and pepper imports. I also find evidence suggesting

that inspection of bean/pea and broccoli/cauliflower imports is conducted to influence terms of trade. I find that inspection of onion imports do not respond to terms of trade considerations. Overall, the evidence suggests that terms of trade do influence border inspections, implying that the US takes advantage of its market power when inspecting vegetable imports.

The structural analysis also quantifies the inspection agency's implied expectation of NIS damage. I find that the inspection agency behaves as if expected NIS damage ranges from \$0 to more than \$0.25 per dollar of inspected imports depending on commodity and season of import. Estimated damage due to tomato imports is constant throughout the year and is estimated at \$0.07 per dollar of imports. I find evidence of seasonal variation in expected damage for some commodities including peppers and onions; in these cases damages are higher in the winter months. With respect to bean/pea and broccoli/cauliflower imports, I find that the inspection agency behaves as if damage due to these imports is very low. The highest estimates of expected damage are associated with onion, pepper, and tomato imports. This is consistent with the relatively high annual domestic production value of these commodities, as well as the political profile of domestic tomato and pepper growers.

This dissertation contributes to the literature on trade and the environment. I provide empirical evidence that an environmental policy is used in a trade-distorting manner, both to protect domestic producers from import competition as well as influence terms of trade. Although there is an extensive theoretical literature addressing the use of environmental policy as a substitute for trade policy, there is

little supporting empirical evidence (Copeland and Taylor 2004 survey this literature). This dissertation is the first to estimate welfare weights implied by enforcement of an environmentally motivated import standard. Prior empirical analyses of trade policy have estimated welfare weights associated with policies explicitly implemented to protect domestic producers from import competition. This dissertation examines enforcement of an import standard implemented to address an environmental externality, but conducted in a trade distorting manner.

A number of previous studies, specifically Goldberg and Maggi (1999) and Bandyopadhyay and Gawande (2000), examine the formation of non-tariff barriers and estimate welfare weights implied by these barriers. These analyses estimate structural parameters using aggregated measures of the stringency of non-tariff barriers based on theoretical models of tariff formation. As presented in the theoretical chapter of this dissertation, the predictions of a model of tariff formation do not necessarily carry over to models of non-tariff barriers. Empirically, I show that it is difficult to derive a priori predictions from a reduced form model of border inspections. I also find that the results of the reduced form analysis imply a lower weight on domestic producer surplus as compared to the results of the structural analysis. The weak connection between theory and empirics in the Goldberg and Maggi (1999) and the Bandyopadhyay and Gawande (2000) analyses may explain the relatively low estimates of producer welfare weights obtained in these studies.

There are a number of potential extensions of this dissertation research. The current analysis assumed that border inspections were conducted irrespective of the country or the region of origin of the trading partner. The empirical analysis can be

extended to test for systematic differences in the application of US trade policy by trading partner, either on the basis of region or on the basis of membership in preferential trade agreements with the US. In future work the empirical framework developed in this dissertation can be extended to studies of border inspection protocols implemented to ensure the safety of food and consumer good imports. Also, an alternative to conducting inspections at the border is greater reliance on pre-clearance programs that move inspection to the point of production. Currently, there is little information on the efficacy of pre-clearance programs (Meilke, Rude, and Zahniser 2008). There is also little information on the trade costs associated with border inspections due to delay and risk of rejection at the border. Future research assessing trade costs due to border inspections, as well as the efficacy and potential cost savings of pre-clearance programs, is clearly needed.

APPENDIX A: Derivation of Comparative Static Results

Price responses:

The equilibrium price arbitrage and materials balance conditions determine domestic price responses as follows:

$$(A.1.1) \quad \frac{dp}{d\tau} = \frac{\frac{\partial x}{\partial p^w}}{-\frac{\partial m}{\partial p} + \frac{\partial x}{\partial p^w}} = \frac{\omega p}{\eta p^w + \omega p}$$

$$(A.1.2) \quad \frac{dp}{dI} = \frac{(b_l + fh_l)\omega p}{\eta p^w + \omega p} = (b_l + fh_l) \frac{dp}{d\tau}$$

$$(A.1.3) \quad \frac{dp}{dq} = \frac{fh_q \omega p}{\eta p^w + \omega p} = fh_q \frac{dp}{d\tau}$$

$$(A.1.4) \quad \frac{dp}{df} = \frac{h\omega p}{\eta p^w + \omega p} = h \frac{dp}{d\tau}$$

$$(A.1.5) \quad \frac{d^2 p}{d\tau^2} = \frac{\frac{\partial^2 x}{\partial (p^w)^2} \frac{dp^w}{d\tau} - \frac{dp}{d\tau} \left[-\frac{\partial^2 m}{\partial p^2} \frac{dp}{d\tau} + \frac{\partial^2 x}{\partial (p^w)^2} \frac{dp^w}{d\tau} \right]}{-\frac{\partial m}{\partial p} + \frac{\partial x}{\partial p^w}}$$

$$(A.1.6) \quad \frac{d^2 p}{d\tau dI} = \frac{\frac{\partial^2 x}{\partial (p^w)^2} \frac{dp^w}{dI} - \frac{dp}{d\tau} \left[-\frac{\partial^2 m}{\partial p^2} \frac{dp}{dI} + \frac{\partial^2 x}{\partial (p^w)^2} \frac{dp^w}{dI} \right]}{-\frac{\partial m}{\partial p} + \frac{\partial x}{\partial p^w}} = (b_l + fh_l) \frac{d^2 p}{d\tau^2}$$

$$(A.1.7) \quad \frac{d^2 p}{d\tau dq} = \frac{\frac{\partial^2 x}{\partial (p^w)^2} \frac{dp^w}{dq} - \frac{dp}{d\tau} \left[-\frac{\partial^2 m}{\partial p^2} \frac{dp}{dq} + \frac{\partial^2 x}{\partial (p^w)^2} \frac{dp^w}{dq} \right]}{-\frac{\partial m}{\partial p} + \frac{\partial x}{\partial p^w}} = fh_q \frac{d^2 p}{d\tau^2}$$

$$(A.1.8) \quad \frac{d^2 p}{d\tau df} = \frac{\frac{\partial^2 x}{\partial (p^w)^2} \frac{dp^w}{df} - \frac{dp}{d\tau} \left[-\frac{\partial^2 m}{\partial p^2} \frac{dp}{df} + \frac{\partial^2 x}{\partial (p^w)^2} \frac{dp^w}{df} \right]}{-\frac{\partial m}{\partial p} + \frac{\partial x}{\partial p^w}} = h \frac{d^2 p}{d\tau^2}$$

Tariff Rate and Inspection Intensity Set Simultaneously:

First order necessary conditions:

$$(A.2.1) \quad \frac{dW(I, \tau)}{d\tau} = \frac{dp}{d\tau} \left\{ -m + (\lambda - 1)y + \frac{\partial m}{\partial p} [\tau + u - kI - \delta(q - h)] \right\} + m = 0$$

$$(A.2.2) \quad \frac{dW(I, \tau)}{dI} = (b_I + fh_I) \frac{dW}{d\tau} - m(b_I + fh_I + k - \delta h_I) = -m(b_I + fh_I + k - \delta h_I) = 0$$

Second order sufficient conditions:

$$(A.2.3) \quad \begin{aligned} \frac{d^2W}{d\tau^2} &= \frac{d^2p}{d\tau^2} \left(\frac{dW}{d\tau} - m \right) / \frac{dp}{d\tau} + \left(\frac{dp}{d\tau} \right)^2 \left\{ -\frac{\partial m}{\partial p} + (\lambda - 1) \frac{\partial y}{\partial p} + \frac{\partial^2 m}{\partial p^2} [T] \right\} + 2 \frac{\partial m}{\partial p} \frac{dp}{d\tau} \\ &= -m \frac{d^2p}{d\tau^2} / \frac{dp}{d\tau} + \left(\frac{dp}{d\tau} \right)^2 \left\{ -\frac{\partial m}{\partial p} + (\lambda - 1) \frac{\partial y}{\partial p} + \frac{\partial^2 m}{\partial p^2} [T] \right\} + 2 \frac{\partial m}{\partial p} \frac{dp}{d\tau} < 0 \end{aligned}$$

(A.2.4)

$$\begin{aligned} \frac{d^2W}{dI^2} &= -m(b_{II} + h_{II}(f - \delta)) + (b_I + fh_I) \frac{d^2W}{d\tau dI} + (b_{II} + fh_{II}) \frac{dW}{d\tau} - \frac{\partial m}{\partial p} \frac{dp}{dI} \frac{(b_I + fh_I)}{m} \frac{dW}{d\tau} \\ &= -m(b_{II} + h_{II}(f - \delta)) + (b_I + fh_I) \frac{d^2W}{d\tau dI} < 0 \end{aligned}$$

where $T = [\tau + u - kI - \delta(q - h(I, q))]$.

Differentiating (A.2.2) with respect to the tariff rate yields:

$$(A.2.5) \quad \frac{d^2W}{dI d\tau} = (b_I + fh_I) \frac{d^2W}{d\tau^2} - \frac{\partial m}{\partial p} \frac{dp}{d\tau} \frac{(b_I + fh_I)}{m} \frac{dW}{d\tau} = (b_I + fh_I) \frac{d^2W}{d\tau^2} < 0$$

The condition for joint concavity of the objective function is derived using (A.2.4) and (A.2.5):

(A.2.6)

$$\begin{aligned} D &= \frac{d^2W}{dI^2} \frac{d^2W}{d\tau^2} - \left(\frac{d^2W}{d\tau dI} \right)^2 = -m(b_{II} + h_{II}(f - \delta)) \frac{d^2W}{d\tau^2} + (b_I + fh_I) \frac{d^2W}{d\tau dI} \frac{d^2W}{d\tau^2} - (b_I + fh_I) \frac{d^2W}{d\tau dI} \frac{d^2W}{d\tau^2} \\ &= -m(b_{II} + h_{II}(f - \delta)) \frac{d^2W}{d\tau^2} > 0 \end{aligned}$$

Assuming concavity of the objective function implies $b_{II} + h_{II}(f - \delta) > 0$.

Second Order Derivatives:

$$(A.2.7) \quad \frac{d^2W}{d\tau d\lambda} = \frac{dp}{d\tau} y \geq 0$$

$$(A.2.8) \quad \frac{d^2W}{d\tau d\delta} = -\frac{\partial m}{\partial p} \frac{dp}{d\tau} (q-h) \geq 0$$

(A.2.9)

$$\begin{aligned} \frac{d^2W}{d\tau dq} &= \frac{d^2p}{d\tau dq} \left(\frac{dW}{d\tau} - m \right) / \frac{dp}{d\tau} + \frac{dp}{d\tau} \frac{dp}{dq} \left\{ -\frac{\partial m}{\partial p} + (\lambda-1) \frac{\partial y}{\partial p} + \frac{\partial^2 m}{\partial p^2} [T] \right\} + \frac{\partial m}{\partial p} \frac{dp}{dq} - \frac{\partial m}{\partial p} \frac{dp}{d\tau} \delta (1-h_q) \\ &= fh_q \left[\frac{d^2W}{d\tau^2} - \frac{\partial m}{\partial p} \frac{dp}{d\tau} \right] - \frac{\partial m}{\partial p} \frac{dp}{d\tau} \delta (1-h_q) \geq 0 \end{aligned}$$

(A.2.10)

$$\begin{aligned} \frac{d^2W}{d\tau df} &= \frac{d^2p}{d\tau df} \left(\frac{dW}{d\tau} - m \right) / \frac{dp}{d\tau} + \frac{dp}{d\tau} \frac{dp}{df} \left\{ -\frac{\partial m}{\partial p} + (\lambda-1) \frac{\partial y}{\partial p} + \frac{\partial^2 m}{\partial p^2} [T] \right\} + \frac{\partial m}{\partial p} \frac{dp}{df} \\ &= h \left[\frac{d^2W}{d\tau^2} - \frac{\partial m}{\partial p} \frac{dp}{d\tau} \right] \geq 0 \end{aligned}$$

$$(A.2.11) \quad \frac{d^2W}{dId\lambda} = (b_l + fh_l) \frac{d^2W}{d\tau d\lambda} \geq 0$$

$$(A.2.12) \quad \frac{d^2W}{dId\delta} = (b_l + fh_l) \frac{d^2W}{d\tau d\delta} + mh_l \geq 0$$

$$\begin{aligned} (A.2.13) \quad \frac{d^2W}{dIdq} &= -mh_{lq} (f - \delta) + (b_l + fh_l) \frac{d^2W}{d\tau dq} + fh_{lq} \frac{dW}{d\tau} - \frac{(b_l + fh_l)}{m} \frac{\partial m}{\partial p} \frac{dp}{dq} \frac{dW}{d\tau} \\ &= -mh_{lq} (f - \delta) + (b_l + fh_l) \frac{d^2W}{d\tau dq} \geq 0 \end{aligned}$$

$$\begin{aligned} (A.2.14) \quad \frac{d^2W}{dIdf} &= -mh_l + (b_l + fh_l) \frac{d^2W}{d\tau df} + h_l \frac{dW}{d\tau} - \frac{\partial m}{\partial p} \frac{dp}{df} \frac{(b_l + fh_l)}{m} \frac{dW}{d\tau} \\ &= -mh_l + (b_l + fh_l) \frac{d^2W}{d\tau df} \geq 0 \end{aligned}$$

Comparative Static Results:

Weight on Domestic Producer Surplus:

(A.2.15)

$$\frac{dI}{d\lambda} = -\frac{\frac{d^2W}{dI d\lambda} \frac{d^2W}{d\tau^2} - \frac{d^2W}{dI d\tau} \frac{d^2W}{d\tau d\lambda}}{D} = -\frac{(b_l + fh_l) \frac{d^2W}{d\tau d\lambda} \frac{d^2W}{d\tau^2} - (b_l + fh_l) \frac{d^2W}{d\tau d\lambda} \frac{d^2W}{d\tau^2}}{D} = 0$$

$$(A.2.16) \quad \frac{d\tau}{d\lambda} = -\frac{\frac{d^2W}{dI^2} \frac{d^2W}{d\tau d\lambda} - \frac{d^2W}{dI d\tau} \frac{d^2W}{dI d\lambda}}{D} = -\frac{\frac{d^2W}{d\tau d\lambda}}{\frac{d^2W}{d\tau^2}} = -\frac{\frac{dp}{d\tau}^y}{\frac{d^2W}{d\tau^2}} \geq 0$$

Expected NIS Damage:

$$(A.2.17) \quad \frac{dI}{d\delta} = -\frac{\frac{d^2W}{dI d\delta} \frac{d^2W}{d\tau^2} - \frac{d^2W}{dI d\tau} \frac{d^2W}{d\tau d\delta}}{D} = -\frac{mh_l \frac{d^2W}{d\tau^2}}{D} \geq 0$$

(A.2.18)

$$\frac{d\tau}{d\delta} = -\frac{\frac{d^2W}{dI^2} \frac{d^2W}{d\tau d\delta} - \frac{d^2W}{dI d\tau} \frac{d^2W}{dI d\delta}}{D} = \frac{m(b_{ll} + fh_{ll} - \delta h_{ll}) \frac{d^2W}{d\tau d\delta} - (b_l + fh_l) mh_l \frac{d^2W}{d\tau^2}}{D} \geq 0$$

Expected Infection Rate:

$$(A.2.19) \quad \frac{dI}{dq} = -\frac{\frac{d^2W}{dI dq} \frac{d^2W}{d\tau^2} - \frac{d^2W}{d\tau dq} \frac{d^2W}{dI d\tau}}{D} = \frac{mh_{lq} (f - \delta) \frac{d^2W}{d\tau^2}}{D} \underset{<}{\geq} 0$$

(A.2.20)

$$\begin{aligned} \frac{d\tau}{dq} &= -\frac{\frac{d^2W}{dI^2} \frac{d^2W}{d\tau dq} - \frac{d^2W}{dId\tau} \frac{d^2W}{dIdq}}{D} = \frac{m(b_{II} + fh_{II} - \delta h_{II}) \frac{d^2W}{d\tau dq} - mh_{Iq}(f - \delta) \frac{d^2W}{d\tau^2} (b_I + fh_I)}{D} \\ &= -\frac{\frac{d^2W}{d\tau dq}}{\frac{d^2W}{d\tau^2}} - \frac{dI}{dq} (b_I + fh_I) \geq 0 \end{aligned}$$

Marginal Treatment Cost:

$$(A.2.21) \quad \frac{dI}{df} = -\frac{\frac{d^2W}{dIdf} \frac{d^2W}{d\tau^2} - \frac{d^2W}{d\tau df} \frac{d^2W}{dId\tau}}{D} = \frac{mh_I}{D} \frac{d^2W}{d\tau^2} \leq 0$$

$$(A.2.22) \quad \frac{d\tau}{df} = -\frac{\frac{d^2W}{dI^2} \frac{d^2W}{d\tau df} - \frac{d^2W}{dId\tau} \frac{d^2W}{dIdf}}{D} = -\frac{\frac{d^2W}{d\tau df}}{\frac{d^2W}{d\tau^2}} - \frac{dI}{df} = \frac{h}{\frac{d^2W}{d\tau^2}} \frac{\partial m}{\partial p} \frac{dp}{d\tau} - h - \frac{dI}{df} \stackrel{>}{<} 0$$

Inspection Intensity Set Independently (Predetermined Tariff Rate):

First Order Necessary Condition:

$$(A.3.1) \quad \frac{dW(I)}{dI} = (b_I + fh_I) \frac{dW}{d\tau} - m(b_I + fh_I + k - \delta h_I) = 0$$

Second Order Sufficient Condition:

$$(A.3.2) \quad \frac{d^2W}{dI^2} = (b_{II} + fh_{II}) \frac{dW}{d\tau} - m(b_{II} + h_{II}(f - \delta)) + (b_I + fh_I) \left[\frac{d^2W}{d\tau dI} + \frac{dW}{d\tau} \frac{\eta}{p} \frac{dp}{dI} \right] < 0$$

Comparative Static Results:

Tariff Rate:

$$(A.3.3) \quad \frac{dI}{d\tau} = -\frac{\frac{d^2W}{dI d\tau}}{\frac{d^2W}{dI^2}} = -\frac{(b_1 + fh_1) \frac{d^2W}{d\tau^2} - \frac{\partial m}{\partial p} \frac{dp}{d\tau} \frac{(b_1 + fh_1) dW}{m d\tau}}{\frac{d^2W}{dI^2}}$$

Weight on Domestic Producer Surplus:

$$(A.3.4) \quad \frac{dI}{d\lambda} = -\frac{\frac{d^2W}{dI d\lambda}}{\frac{d^2W}{dI^2}} = -\frac{(b_1 + fh_1) \frac{d^2W}{d\tau d\lambda}}{\frac{d^2W}{dI^2}} = -\frac{(b_1 + fh_1) \frac{dp}{d\tau} y}{\frac{d^2W}{dI^2}} > 0$$

Expected NIS Damage:

$$(A.3.5) \quad \frac{dI}{d\delta} = -\frac{\frac{d^2W}{dI d\delta}}{\frac{d^2W}{dI^2}} = -\frac{mh_1 + (b_1 + fh_1) \frac{d^2W}{d\tau d\delta}}{\frac{d^2W}{dI^2}} = -\frac{mh_1 - \frac{\partial m}{\partial p} \frac{dp}{dI} (q - h)}{\frac{d^2W}{dI^2}} > 0$$

Expected Infection Rate:

(A.3.6)

$$\frac{dI}{dq} = -\frac{\frac{d^2W}{dI dq}}{\frac{d^2W}{dI^2}} = -\frac{-mh_{1q} (f - \delta) + (b_1 + fh_1) \frac{d^2W}{d\tau dq} + fh_{1q} \frac{dW}{d\tau} - \frac{(b_1 + fh_1) \frac{\partial m}{\partial p} \frac{dp}{dq} \frac{dW}{d\tau}}{m}}{\frac{d^2W}{dI^2}} \begin{matrix} \geq 0 \\ < 0 \end{matrix}$$

Marginal treatment cost:

$$(A.3.7) \quad \frac{dI}{df} = -\frac{\frac{d^2W}{dI df}}{\frac{d^2W}{dI^2}} = -\frac{-mh_1 + (b_1 + fh_1) \frac{d^2W}{d\tau df} + h_1 \frac{dW}{d\tau} - \frac{\partial m}{\partial p} \frac{dp}{df} \frac{(b_1 + fh_1) dW}{m d\tau}}{\frac{d^2W}{dI^2}} \begin{matrix} \geq 0 \\ < 0 \end{matrix}$$

APPENDIX B: PPQ 280 Disposition Codes

DISPOSITION CODES	Definition of code:
CCNA	Cargo Clearance, No Action - Regulated Product released based solely on review of entry documents or verification of temperature logs. Shipment was not held for further inspection. This does not include BCR or NCR shipments. Example: Litchi from China undergoing Cold Treatment while in transit to the U.S. and no inspection was required.
CTPT	Cold Treatment, Precautionary Treatment – The product was sent to a cold-treatment facility in U.S. to undergo cold treatment to meet entry requirements.
DEAP	Destroyed, Actionable Pest - Product destroyed because an actionable pest was found on, in, or with the product.
DEAR	Destroyed Actionable Pest on NARP - The commodity on the NARP list was destroyed because the product was infested with an actionable pest. The destruction was the result of a NARP commodity selected for an intensive inspection resulting in the pest being found. Use DEAP if the commodity was commingled with non-NARP commodities.
DECC	Destroyed, Carrier Contamination - Product destroyed because of container contamination with non-enterable products such as citrus leaves, soil, blood, or noxious weed seeds.
DEPC	Destroyed, Product Contamination - Destroyed because product was contaminated with another non-enterable product such as citrus leaves, soil, blood, or noxious weed seeds on the product.
DEPD	Destroyed, Phyto Discrepancy - Commodity destroyed due to discrepancy on the phytosanitary certificate. For example, a discrepancy may be defined as wrong commodity, quantity, weight, or lack of a phyto or Additional Declaration
DEPP	Destroyed, Prohibited Product - Commodity was destroyed because it was prohibited from entering the U.S.
DPRP	Departmental Permit, Restricted Prohibited - Product restricted or prohibited entering in accordance with a Departmental Permit. These usually are samples going for testing.
ENPE	Entered, Post Entry - Product entered under Post-entry requirements. These are live plants requiring quarantine upon entry for two years.
ESRC	Endangered Species, Rescue Center – CITES plants that are seized and sent to an approved rescue center.

FUAP	Fumigated, Actionable Pest - Product was fumigated because an actionable pest was found associated with the product.
FUAR	Fumigated Actionable Pest on NARP – The commodity on the NARP list was fumigated because the product was infested with an actionable pest. This fumigation was the result of a NARP commodity selected for an intensive inspection resulting in the pest being found. Use FUAP if the commodity was commingled with non-NARP commodities.
FUCC	Fumigated, Carrier Contamination - Product was fumigated because of container contamination.
FUPC	Fumigated, Product Contamination - Product was fumigated because of product contamination such as soil.
FUPQ	Fumigated Precautionary - Fumigated a potential quarantine pest that was fumigated before final determination of the pest. (For other treatments use OTPQ.)
FUPT	Fumigated, Precautionary Treatment – As a condition of entry product was fumigated as a precautionary treatment to meet entry requirements.
IEND	Immediate Export, No Diversions – Product failed to make entry requirements of the US and the shipment was allowed to be exported to another country. Example: Product was shipped from Turkey and did not meet U.S. requirements. Shipper requested product be shipped to Canada.
IRBC	Inspected and Released, Border Cargo - Agricultural product on the line release program or BRASS program was randomly inspected and released.
IRAR	Inspected and Release Agriculture Release (NARP) - Inspected and Released Agriculture Release (Program): NARP shipments that have been inspected and found in compliance of all regulations.
IRMR	Inspected and Released, Meets Requirements – Product was released after a <u>physical inspection</u> of the commodity revealed no pest or contaminants of quarantine significance. Include cold treated transit commodities that are inspected upon entry into the U.S.
IRPD	Inspected and Released, Phyto Discrepancy - Commodity inspected and released after discrepancy on the phytosanitary certificate has been reconciled to meet U.S. entry requirements. For example, a discrepancy may be defined as wrong commodity, quantity, weight, or lack of a phyto or Additional Declaration (AD). A reconciled phyto would include a superseded phyto to correct such items as an AD, quantity, etc. Also a new phyto may be issued by the exporting country to cover the shipment. The shipment would be held pending a superseded or new phyto, but the inspection was performed to enter U.S. commerce.

OTAP	Other Action Taken, Actionable Pest – The actions taken on the commodity were approved methods to destroy the pest other than fumigation. Examples would include hot water dips, heat treatments, grinding, or irradiation. The commodity is allowed to enter U.S. commerce after the treatment is complete.
OTAR	Other Action Taken on NARP - The commodity on the NARP list had other remedial actions taken. The remedial action was the result of a NARP commodity selected for an intensive inspection resulting in precautionary treatment for a pest, carrier, or contamination with a pest. The remedial action of cleaning, reconditioning, use of non-fumigants, etc... resulted in the commodity meeting the entry requirements of the United States. Use the “OT __” codes if the commodity was commingled with non-NARP commodities.
OTCC	Other Action Taken, Carrier Contamination - Action taken on product because of carrier contamination. Pest-free product was transferred, cleaned, and allowed to enter the U.S. commerce. Mostly used at land border locations. Examples include the following: Containers or trucks with noxious weeds, soil, manure, straw, etc. were steam cleaned or transferred to a clean carrier.
OTPC	Other Action Taken, Product Contamination - Action taken on product because of product contamination. Product was cleaned and allowed to enter the U.S. commerce. Example: Citrus leaves were removed from a shipment of limes.
OTPP	Other Action Taken, Prohibited Product – Other action taken on product because it was prohibited from entering the U.S.
OTPQ	Other Action taken Precautionary – Any treatment other than fumigation used when a potential quarantine pest is found and the final determination has not yet been met.
OTPT	Other Action Taken, Precautionary Treatment - Other treatment not fumigation that are required as condition of entry used on products not requiring cold-treatment or fumigation. Other treatments may include heat-treatments on such commodities as Niger seed, or dips on certain plants to make them enterable into U.S. commerce. These would include mandatory treatments upon entry into the U.S.
PCNA	Pre-cleared, No Action – Product was inspected and released for U.S. commerce in another country. No further inspections were performed on the shipment upon entry into the U.S. Example would be Chilean grapes inspected before it departed the country of origin.
PCIR	Pre-cleared, Inspected and Release - Product was inspected and released for U.S. commerce in another country. Upon entry into the U.S.,

	the product was randomly inspected at port of entry to monitor the pre-clearance program or to conform to pre-clearance protocols.
REAR	Released Agriculture Release program (NARP): NARP shipments that entered the country under the NARP Program and were not inspected.
REBC	Released, Border Cargo Release Program - Agricultural product on the line release program or BRASS program was released without inspection at the port of entry.
RXAP	Returned, Actionable Pest - Product re-exported to the country of origin because an actionable pest was found on the product.
RXAR	Returned Actionable Pest on NARP – The commodity on the NARP list was returned back to the country of origin because the product was infested with an actionable pest. The re-exportation was the result of a NARP commodity selected for an intensive inspection resulting in the pest being found. Use RXAP if the commodity was commingled with non-NARP commodities.
RXCC	Returned, Carrier Contamination – Product and carrier re-exported to the country of origin because of carrier contamination. Used mostly at land border locations. These shipments consist of containers or trucks with prohibited noxious weeds, blood, soil, manure, straw, etc. re-exported to the country of origin.
RXPC	Returned, Product Contamination - Product was re-exported back to another country because of product contamination with non-enterable products such as citrus leaves, soil, manure, or noxious weeds.
RXPD	Returned, Phyto Discrepancy - Commodity re-exported the country of origin due to discrepancy on the phytosanitary certificate. For example, a discrepancy may be defined as wrong commodity, quantity, weight, or lack of a phyto or Additional Declaration (AD).
RXPP	Returned, Prohibited Product - Product was re-exported to the country of origin. Commodity was not approved for entry into the U.S.
RXPQ	Returned Precautionary – Any shipment where importer opts no re-export based on potential quarantine pest prior to final ID.
RXWP	Returned - Wood Packaging Material Violation: returned violation in ISPM15.
TEOC	Transit and Export, Other Country - Product makes entry, only to transit under CBP in-bond (7512) to another U.S. port before it is exported to another country.

Bibliography

Ahn, Byeong-Il and Daniel A. Sumner. 2009. Political Market Power Reflected in Milk Pricing Regulations, *American Journal of Agricultural Economics*, forthcoming

Ameden, Holly C., Sean A. Cash, and David Zilberman. 2007. Border Enforcement and Firm Response in the Management of Invasive Species, *Journal of Agricultural and Applied Economics* 39: 35-46.

Avery, William P. 1998. Domestic Interests in NAFTA Bargaining, *Political Science Quarterly* 113(2): 281-305.

Bagwell, Kyle and Robert W. Staiger. 2006. What do Trade Negotiators Negotiate About? Empirical Evidence from the World Trade Organization. NBER Working Paper No. 12727

Batabyal, Amit and Hamid Beladi. 2009. Trade, the Damage from Alien Species, and the Effects of Protectionism under Alternate Market Structures. *Journal of Economic Behavior and Organization* 70(1-2): 389-401.

Baylis, Kathy and Jeffrey M. Perloff. 2010. Trade Diversion from Tomato Suspension Agreements. *Canadian Journal of Economics*. Forthcoming. Available at: http://works.bepress.com/kathy_baylis/22

Beghin, John. 2008. Non-tariff Barriers. *The New Palgrave Dictionary of Economics*. Second Edition. Eds. Steven N. Durlauf and Lawrence E. Blume. Palgrave Macmillan,. The New Palgrave Dictionary of Economics Online. Palgrave Macmillan. 17 October 2008
<http://www.dictionaryofeconomics.com/article?id=pde2008_N000169>
doi:10.1057/9780230226203.1202

Beghin, John C. and Jean-Christophe Bureau. 2001. Quantitative Policy Analysis of Sanitary, Phytosanitary and Technical Barriers to Trade. *Economie Internationale* 3(87):107-130.

Bockstael, Nancy E. 1984. The Welfare Implications of Minimum Quality Standards. *American Journal of Agricultural Economics* 66:466-471.

Bredahl, Maury, Andrew Schmitz, and Jimmye S. Hillman. 1987. Rent Seeking in International Trade: The Great Tomato War. *American Journal of Agricultural Economics* 69(1):1-10.

Broda, Christian, Nuno Limao, and David E. Weinstein. 2008. Optimal Tariffs and Market Power: The Evidence. *American Economic Review*, 98(5):2032-2065.

- Broda, Christian and David E. Weinstein. 2006. Globalization and the Gains from Variety. *Quarterly Journal of Economics*, 121(2): 541-585.
- Burton, Diana M., H. Alan Love, and Gordon C. Rausser. 2004. Estimating Statistical Properties of Political Economic Decisions. *Applied Economics*, 36: 1489-1499.
- Calvin, Linda and Veronica Barrios. 1998. Marketing Winter Vegetables from Mexico. Economic Research Service, Vegetables and Specialties/VGS-274/April.
- Calvin, Linda, Barry Krissoff, and William Foster. 2008. Measuring the Cost and Trade Effects of Phytosanitary Protocols: A US-Japanese Apple Example. *Review of Agricultural Economics*, 30(1): 120-135.
- Campbell, Kate. 2007. Bill Would Move Ag Inspections Back to USDA. California Farm Bureau Federation
<http://www.cfbf.com/agalert/AgAlertStory.cfm?ID=788&ck=C15DA1F2B5E5ED6E6837A3802F0D1593>
- Copeland, Brian and Scott Taylor. 2004. Trade, Growth, and the Environment. *Journal of Economic Literature*, 62(March): 7-71.
- Costello, Christopher, Chad Lawley, and Carol McAusland. 2009. "Pre-empting Non-indigenous Species Introductions: Targeting Policy", forthcoming in *Handbook on Trade and the Environment*, Edward Elgar Press.
- Costello, Christopher, Mike Springborn, Carol McAusland, and Andy Solow. 2007. Unintended Biological Invasions: Does Risk Vary by Trading Partner? *Journal of Environmental Economics and Management*, 54(3): 262-276.
- Eichenbaum, Martin, Lars Hansen, and Kenneth Singleton. 1988. A Time Series Analysis of Representative Agent Models of Consumption and Leisure Under Uncertainty. *Quarterly Journal of Economics*, 103(1): 51-78.
- Eichenbaum, Martin. 1989. Some Empirical Evidence on the Production Level and Production Cost Smoothing Models of Inventory Investment. *American Economic Review*, 79(4): 853-864.
- Eicher, Theo and Thomas Osang. 2002. Protection for Sale: An Empirical Investigation: Comment. *American Economic Review*, 92(5):1702-1710.
- Feenstra, Robert C. 1994. New Product Varieties and the Measurement of International Prices. *American Economic Review*, 84(1): 157-77.
- Fischer, Ronald and Pablo Serra. 2000. Standards and Protection. *Journal of International Economics*, 52: 377-400.

US General Accounting Office (GAO). 2008. Federal User Fees: Substantive Reviews Needed to Align Port-Related Fees to the Programs they Support. GAO-08-321. <http://www.gao.gov/new.items/d08321.pdf>

US General Accounting Office (GAO). 2006. Homeland Security: Management and Coordination Problems Increase the Vulnerability of US Agriculture to Foreign Pests and Disease. GAO-06-644. <http://www.gao.gov/new.items/d06644.pdf>

US General Accounting Office (GAO). 1997. Agricultural Inspection: Improvements Needed to Minimize Threat of Foreign Pests and Diseases. Report to Congressional Committees. GAO/RCED-97-102. <http://www.gao.gov/archive/1997/rc97102.pdf>

Gawande, Kishore and Usree Bandyopadhyay. 2000. Is Protection for Sale? Evidence on the Grossman-Helpman Theory of Endogenous Protection. *The Review of Economics and Statistics* 82(1): 139-152.

Goldberg, Pinelopi K. and Giovanni Maggi 1999. Protection for Sale: An Empirical Investigation. *American Economic Review* 89(5): 1135-1155.

Grossman, Gene M. and Elhanan Helpman. 1994. Protection for Sale. *American Economic Review* 84(4): 833-50.

Hansen, Lars P. 1982. Large Sample Properties of Generalized Method of Moments Estimators. *Econometrica* 50(4): 1029-1054.

Huang, Sophia and Kuo Huang. 2007. Increased US Imports of Fresh Fruits and Vegetables. Economic Research Service/USDA FTS-328-01.

Josling, Tim, Donna Roberts, and David Orden. 2004. *Food Regulation and Trade: Towards a Safe and Open Global System*. Institute for International Economics: Washington, D.C.

Kreith, Marcia and Deborah Golino. 2003. Regulatory Framework and Institutional Players, In D.A. Sumner, ed., *Exotic Pests and Diseases: Biology and Economics for Biosecurity*, Ames: Iowa State Press.

Lee, Jong-Wha and Phillip Swagel. 1997. Trade Barriers and Trade Flows across Countries and Industries. *The Review of Economics and Statistics* 79(3): 372-382.

Liu, Lan and Chengyan Yue. 2009. Non-tariff Barriers to Trade Caused by SPS Measures and Customs Procedures with Product Quality Changes. *Journal of Agricultural and Resource Economics* 34(1): 196-212.

Lopez , Rigoberto A. and Xenia Matschke. 2006. Food Protection for Sale. *Review of International Economics* 14(3): 380–391.

- Lynch, Lori. 2002. Migration of Exotic Pests: Phytosanitary Regulations and Cooperative Policies to Protect US Ecosystems and Agricultural Interests. In L. Fernandez and R.T. Carson, eds., *Both Sides of the Border: Transboundary Environmental Management Issues Facing Mexico and the United States*. Norwell, MA: Kluwer.
- Margolis, Michael, Jason F. Shogren, and Carolyn Fischer. 2005. How Trade Politics Affect Invasive NIS Control. *Ecological Economics* 52: 305-313.
- Margolis, Michael and Jason F. Shogren. 2007. The Political Economy of Disguised Protectionism and Contaminated Imports. Working paper.
- Margosian, Margaret L., Christie A. Bertone, Daniel M. Borchert, and Yu Takeuchi. ND. Identification of Areas Susceptible to the Establishment of Fifty-three *Bactrocera* spp. (Diptera: Tephritidae: Dacinae) in the United States. APHIS, http://www.aphis.usda.gov/plant_health/plant_pest_info/fruit_flies/downloads/bactrocera-susceptibility-analysis.pdf
- McCullough, Deborah G., Timothy T. Work, Joseph F. Cavey, Andrew M. Liebhold, and David Marshall. 2006. Interceptions of Nonindigenous Plant Pests at US Ports of Entry and Border Crossings over a 17-year Period. *Biological Invasions* 8: 611-630.
- McAusland, Carol and Christopher Costello. 2004. Avoiding Invasives: Trade-related Policies for Controlling Unintentional Exotic Species Introductions. *Journal of Environmental Economics and Management* 48(2): 954-977.
- Meilke, Karl, James Rude, and Steven Zahniser. 2008. Is 'NAFTA Plus' an Option in the North American Agrifood Sector? *The World Economy*, 31(7): 925-946.
- Merel, Pierre R. and Colin A. Carter. 2008. A Second Look at Managing Import Risk from Invasive Species. *Journal of Environmental Economics and Management*, 56(3): 286-290.
- Mumford, J.D. 2002. Economics Issues Related to Quarantine in International Trade. *European Review of Agricultural Economics*, 29(3): 329-348.
- National Research Council (NRC). 2002. *Predicting Invasions of Non-indigenous Plants and Plant Pests*. National Academy Press, Washington, D.C.
- Newey, Whitney K. and Kenneth D. West. 1987. A Simple Positive Semi-definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix. *Econometrica* 55(3): 703-708.
- Oehmke, James F. and Xianbin Yao. 1990. A Policy Preference Function for Government Intervention in the US Wheat Market. *American Journal of Agricultural Economics* 72: 631-640.

- Office of Technology Assessment (OTA). 1993. Harmful Non-Indigenous NIS in the United States. Office of Technology Assessment, United States Congress, Washington, DC.
- Orden, David. 1996. Agricultural Interest Groups and the North American Free Trade Agreement, In Anne O. Krueger, ed., *The Political Economy of American Trade Policy*, Chicago and London: The University of Chicago Press.
- Paarlberg, Philip L. and John G. Lee. 1998. Import Restrictions in the Presence of a Health Risk: An Illustration using FMD. *American Journal of Agricultural Economics* 80(1): 175-183.
- Perrings, Charles, Katharina Dehnen-Schmutz, Julia Touza, and Mark Williamson. 2005. How to Manage Biological Invasions under Globalization. *Trends in Ecology and Evolution*. 20(5): 212-215.
- Peterson, Everett B. and David Orden. 2008. Avocado Pests and Avocado Trade. *American Journal of Agricultural Economics* 90(2): 321-335.
- Rawson, Jean M. 2002. Homeland Security Department: UD Department of Agriculture Issues, Report for Congress, Order Code RL31466.
- Ray, Edward J. 1981. Tariff and Nontariff Barriers to Trade in the United States and Abroad. *The Review of Economics and Statistics* 63(2): 161-168.
- Rigobon, Roberto. 2003. Identification through Heteroskedasticity. *The Review of Economics and Statistics* 85(4):777-92.
- Sequeira, R., L. Millar, and D. Bartels. 2001. Identification of Susceptible Areas for the Establishment of *Anastrepha* spp. Fruit Flies in the United States and Analysis of Selected Pathways. APHIS, http://www.aphis.usda.gov/plant_health/plant_pest_info/fruit_flies/downloads/isa.pdf
- Smith, James. 2003. International Trade Agreements and Sanitary and Phytosanitary Measures, In D.A. Sumner, ed., *Exotic Pests and Diseases: Biology and Economics for Biosecurity*, Ames: Iowa State Press.
- Sumner, Daniel A. and Stefan Tangermann. 2002. International Trade Policy and Negotiations, In Bruce Gardner and Gordon Rausser, eds., *Handbook of Agricultural Economics, Volume 2*, Elsevier Science.
- Trefler, Daniel. 1993. Trade Liberalization and the Theory of Endogenous Protection: An Econometric Study of US Import Policy. *Journal of Political Economy* 101(1): 138-160.

US International Trade Commission (USITC). 2007. Monitoring of US Imports of Peppers. USITC Publication 3960. Investigation No. 332-351.

Venette, Robert C., Roger D. Moon, and William D. Hutchinson. 2002. Strategies and Statistics of Sampling for Rare Individuals. *Annual Review of Entomology* 47:143-174.

Vitousek, Peter M., Carla M. D'Antonio, Llyod L. Loope, Marcel Rejmanek, and Randy Westbrooks. 1997. Introduced NIS: A Significant Component of Human-caused Global Change. *New Zealand Journal of Ecology* 21(1): 1-16.

Waage, J.K. and J.D. Mumford. 2008. Agricultural Biosecurity. *Philosophical Transactions of the Royal Society B*, 363: 863-876.

Wilson, Norbert L. W. and Jesus Anton. 2006. Combining Risk Assessment and Economics in Managing a Sanitary-phytosanitary Risk. *American Journal of Agricultural Economics* 88(1): 194-202.

Work, Timothy T., Deborah G. McCullough, Joseph F. Cavey, and Ronald Komsa. 2005. Arrival Rates of Nonindigenous Insect Species into the United States through Foreign Trade. *Biological Invasions* 7: 323-332.

Yue, Chengyan, John C. Beghin, and Helen H. Jensen. 2006. Tariff Equivalent of Technical Barriers to Trade with Imperfect Substitution and Trade Costs. *American Journal of Agricultural Economics* 88(4): 947-960.