# ESSAYS ON DETERMINANTS OF ENVIRONMENTAL OUTCOMES,

# AND AGRICULTURAL POLICY

By

YEON A HONG

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the dissertation of YEON A HONG find it satisfactory and recommend that it be accepted.

_____________________________________
Gregmar I. Galinato, Ph.D., Co-Chair

_____________________________________
R. Karina Gallardo, Ph.D., Co-Chair

_____________________________________
Jill J. McCluskey, Ph.D.

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ESSAYS ON DETERMINANTS OF ENVIRONMENTAL OUTCOMES,

AND AGRICULTURAL POLICY

Abstract

by Yeon A Hong, Ph.D.
Washington State University
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Co-Chairs: Gregmar I. Galinato and R. Karina Gallardo

This dissertation consists of three papers on integrating social, economic, and political influences on food choice behavior and environmental outcomes and assessing agricultural policy. The first paper analyzes the effects of religious beliefs and homogeneity on meat consumption and related greenhouse gas emissions using a unique dataset on religion prevalence. The empirical evidence suggests that the religious effect on the individuals' dietary choice considerably varies from religion to religion, and in a more heterogeneous society, individuals are less willing to follow religious dietary laws. The second paper measures the effect of the planner's academic background on a pollution indicator using panel data on university majors of heads of state in autocratic countries. The results show that an academic major of heads of state leads to a significant change in sulfur dioxide emissions in the autocratic sample, but the individual characteristics does not make any influence in the democratic country sample. The third paper assesses the economic impact of apple maggot infestation in Washington State by the pest quarantine status and by the existence of phytosanitary trade regulations under an apple maggot quarantine program and provides the Washington State government agency with policy implications for deciding the stringency of pest management programs.

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## Dedication

I dedicate this dissertation to my sister, Yun Jeong Hong.

# CHAPTER ONE

# INTRODUCTION

This dissertation consists of three papers. It includes a study on the role of religion as a determinant of an individual's dietary choice and greenhouse gas emissions from meat consumption, an analysis on the process of environmental policy formation in autocratic regimes with respect to a government planner's sensitivity to pollution shaped in education, and a policy evaluation on how phytosanitary regulations affect apple producers' profitability.

The first paper (Chapter Two) addresses the role of religion in determining an individual's dietary choice of livestock products. It tests the effects of religious beliefs and homogeneity on consumption of livestock products and greenhouse gas emissions, utilizing a unique dataset on religion prevalence. The empirical evidence suggests that the religious effects considerably vary from religion to religion, and in a more heterogeneous society, individuals are less willing to follow religious dietary laws. The significance of the result is interesting from a policy standpoint since this will allow us to assess how changes in a society's religious landscape due to migration and/or political violence would affect demand for livestock products and consequently GHG emissions from the livestock sector.

The second paper (Chapter Three) focuses on a government planner's educational background to find the mechanism underlying the process of environmental policy formation in autocratic regimes with limited political channels for the public to express their demands for environmental amenities. It models how a government planner's academic discipline shapes their environmental preferences. In autocratic regimes, such environmental preferences directly affect pollution level, but in democratic regimes the influence of the individual characteristics on the stringency of such regulations becomes limited due to lobbying activities. The theoretical linkage is tested, using a novel panel data on a university major of heads of state. The empirical findings suggest that a head of state educated in business/economics leads to a greater increase in sulfur dioxide emissions relative to heads of state educated in a different discipline from business/economics in the autocratic country sample, while the relative negative effect of the discipline disappears in the democratic country sample.

The objective of the third paper (Chapter Four) is to assess the economic impact of a potential increase in the risk of apple maggot infestation and apple maggot quarantine areas in Washington State, and the consequences on producers' profitability given the phytosanitary trade regulations with key international commercial partners. It presents a model where the representative apple producer's management problem is to control invasive species. One finds that, at the steady state, the optimal pesticide use increases in the cost burden to meet the phytosanitary regulations. We simulate the cost of the pest management strategy reflected by the number of pesticide applications and profits at the orchard level under four scenarios varying in the level of infestation—expressed as quarantine status—and the existence of the regulations requiring an additional period of cold storage. The results show that an increasing cost burden due to the phytosanitary regulations of British Columbia, Canada and China that require apples coming from apple maggot quarantine areas be in cold storage prior to export raises the optimal number of pesticide applications to prevent the risk of increasing apple maggot infestation and quarantine areas. This study is useful in measuring the orchard-level benefits of preventing apple-maggot expansion in Washington State and provides the Washington State government agency with policy implications on the importance of programs minimizing the risk of apple maggot infestation in pest-free areas.

CHAPTER TWO

# THE EFFECT OF RELIGION ON MEAT CONSUMPTION AND GREENHOUSE GAS EMISSIONS


## Abstract

This study analyzes the effects of religious beliefs and homogeneity on meat consumption and related greenhouse gas (GHG) emissions. We model how religion influences a household’s consumption decision between socially accepted and discouraged goods. The equilibrium quantities of goods consumed due to religious influence determine aggregate emissions. Using a unique dataset on religion, we find that Hinduism and Islam significantly affect meat consumption and GHG emissions. The empirical estimates show that an increase in the proportion of Hindu population reduces consumption of beef, but the negative effect diminishes as a society becomes more religiously heterogeneous. This result suggests that individuals living in societies that are more heterogeneous are less willing to follow religious norms. We also find that 1% increase in Muslim population induces a decrease in per capita GHG emissions from pork consumption by 4.06%.

## 1. Introduction

The livestock sector plays a significant role in climate change, contributing 14.5% of total human-induced greenhouse gas (GHG) emissions (Gerber et al., 2013). The sector's GHG emissions are projected to increase as the share of livestock products in the diet continues to grow, particularly in developing economies (Fiala, 2008; Keyzer, 2005; Morrison et al., 2003; Popp, 2010; Stehfest et al., 2009). Many studies have suggested direct factors that cause individuals' dietary habits to shift, including growth in population and income level as well as urbanization (Rae, 1998; Steinfeld, 2007; York and Gossard, 2004). Delgado (2003) explains that individuals tend to diversify their diets by consuming more animal-based foods such as meat and dairy products to obtain adequate levels of essential nutrients as income rises and individuals become urbanized. The globalization of food systems—necessarily accompanied by greater food availability and diversity—is also considered one of the main drivers of changes in dietary patterns (Kennedy et al. 2004; de Haan et al., 2003; Haddad, 2003; Popkin, 2003; Reardon et al., 2003).[1]

Even with the emergence of various factors that could shift dietary patterns, religious teachings affect an individual's social behavior, such as the purchase of food items (Iannaccone, 1998). Some religions restrict an individual's dietary choices. For example, Islam forbids pork consumption, and Hinduism restricts both beef and pork (Table 1). The influence of religion on

[1] For example, in Japan, seafood, traditionally the primary protein source, has been gradually replaced by meat (Tokoyama et al., 2002). Non-traditional foods, bread, and milk, are commonly consumed in China and have become a significant part of urban Chinese breakfasts (Bai et al, 2014).

food consumption depends on the religion itself and on the extent to which individuals follow religious practices (Bonne and Verbeke, 2008). The extent of conformity to such practices could vary according to characteristics of the society to which they belong, such as the share of their religious group in the society and the society's tolerance of diversity (Alesina et al., 2003). European consumers belonging to native and ethnic groups are inclined to alter their traditional diet favoring mixed food habits due to Europe's multicultural nature and globalization of the food supply (Gilbert and Khokhar, 2008; Koctürk, 1996).

Table 1. Dietary Restrictions by Religion

| Religion | Dietary restrictions |
| --- | --- |
| Hinduism | Pork and beef |
| Islam | Pork and not ritually slaughtered meat |
| Buddhism | Pork and beef |
| Christianity | None |

Source: Bonne and Verbeke (2008) and Sack (2001)

This study investigates how religion impacts individuals' consumption decision over animal products and evaluates its impact on GHG emissions. First, we adapt a static general equilibrium model in which religion constrains a household's choice between socially accepted and discouraged goods to show that in equilibrium a household consumes less of a social discouraged good if the society to which they belong is more religiously homogeneous. Second, we test the theoretical linkage in our model by estimating the effect of religious homogeneity and type of religion on meat consumption and then calculate the religion elasticity of GHG emissions from meat consumption. This is the first study to theoretically link and empirically measure how religion affects GHG emissions through meat consumption.

This study contributes to the literature on the determinants of dietary change. Because of a growing openness to international markets, diets in the developing world are shifting rapidly with respect to fat, caloric sweeteners, and animal-based foods, a combination that is often referred to as the "Western diet" (Popkin, 2003; Popkin et al, 2012). Chinese consumers have responded by dramatically increasing consumption of meat and dairy products and by decreasing consumption of grain-based foods (Dong and Fuller, 2010). A similar consumption pattern for animal-protein products has occurred in Indonesia, where consumers have shifted from fish to dairy and meat products (Fabiosa, 2005). Pingali (2006) points out that the convergence towards a Western diet is reinforced by the rapid spread of global supermarket chains and fast food restaurants. The fresh market is disappearing as the major source of food in developing countries, and is being replaced by large regional and multinational chains (Popkin, 2003). This transformation in food retailing allows consumers to be exposed to diverse diets and new, dairy-intensive food items (Beghin, 2006; Gereffi, 2010).

When a variety of foods are available due to delocalized food supplies, cultural preferences for food could still play a critical role in selecting food items (Kuhnlein and Receveur, 1996). Alexandratos and Bruinsam (2012) and the Food and Agriculture Organization of the United Nations (2009) demonstrate that cultural or religious aspects can impact local demand for livestock commodities based on their observation of the food consumption pattern in India, where—unlike in China and Brazil—meat consumption has not accompanied income growth because of the vegetarian tradition and religious culture that restrict beef and pork consumption (Leitzmann, 2014; Mohanty et al., 1998; Steinfeld, 2007). York and Gossard (2004) show that the relationship between modernization and meat consumption differs significantly across geographic regions.

What has been lacking from this literature is a framework that explains why and how the religious component is transmitted to an individual's dietary decision when faced with the availability of diverse food products. Furthermore, the interpretation of the role of religion in the literature is intuitive but limited in the absence of an actual measure of the religious factor. This study attempts to fill this void by providing a conceptual framework relating religion to individuals' dietary choice, incorporating an aspect of identity. More importantly, we directly measure the effect of religious homogeneity, applying a unique panel dataset that indicates the religious prevalence of four major religions.

Each major world religion has different ideal behaviors for adherents. Individuals follow these prescriptions to maintain the identity shaped by their religious belief. Akerlof and Kranton (2000) illustrate that social categories—religious categories in this context—are associated with prescribed behaviors and that identity is fundamental to these behaviors. However, the extent of concern with religious identity can vary across individuals even within the same religious tradition. If an individual lives in a society that is highly religiously heterogeneous, he or she is more inclined to behave in such a way that "no norm is necessarily correct and become loose in following norms" (Triandis, 1994, p. 160). In contrast, if an individual lives in a religiously homogeneous society, he or she is less inclined to deviate from normative behavior because of potentially severe sanctions administered to deviants (Triandis, 1994, 2001). Thus, a high degree of religious homogeneity in the society is an incentive to follow prescriptions to an individual concerned with identity.

Based on the literature of identity economics (Akerlof, 2008; Benjamin et al., 2010), we adapt a static general equilibrium model in which a household's concern with religious identity constrains a household's choice between socially accepted and discouraged goods. A household weighs a socially accepted good and a discouraged good when choosing the composition of consumption. The household's weight is dependent on the degree of religious homogeneity within a society. We show that, in equilibrium, a household consumes less of a socially discouraged good when society is more religiously homogeneous. The equilibrium quantity of a good is determined by both the weight of one household that considers the good socially accepted and the weight of another that considers the good socially discouraged. The equilibrium quantity of the good contributes to GHG emissions.

To test the theoretical results, we use a panel dataset from FAOSTAT on meat consumption and GHG emission intensity of meat. The dataset includes 130 countries and spans from 2002 to 2013. The FAOSTAT data are matched with unique data on religion prevalence from multiple sources and an index of religious heterogeneity. Religion prevalence indicates the proportion of population believing in one of the four major religions: Christianity, Buddhism, Islam, and Hinduism. We create a unique panel dataset of an index of religious heterogeneity using the measure of fractionalization in Alesina et al. (2003). Our identication strategy is to break the link from religion on GHG emissions into two steps. We first conduct estimations to measure the effects of religions on consumption of meat products, and then combine the parameters found through the estimations with per unit pollution damage of production, as measured by the emission intensity of meat products.

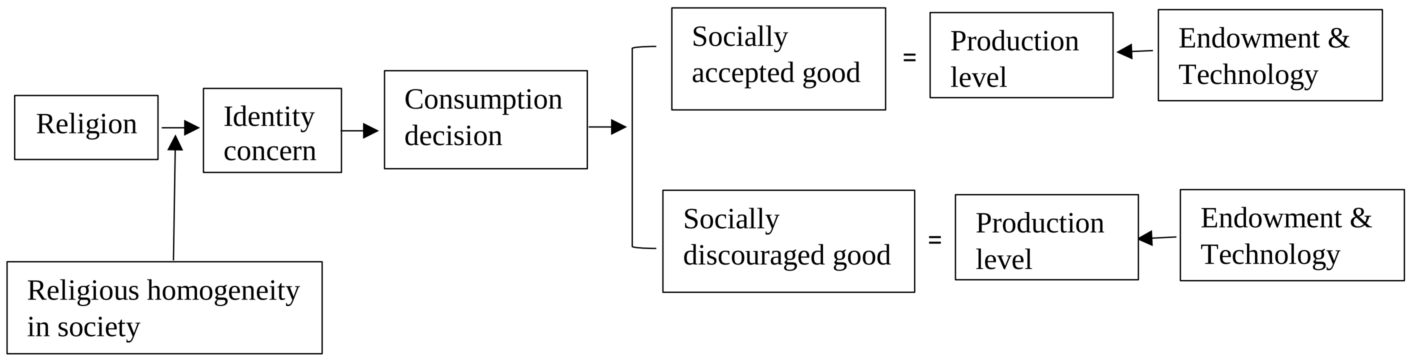
We find that an increase in the proportion of Hindu population reduces consumption of beef, but the negative effect diminishes as a society becomes more religiously heterogeneous. A one-unit increase in the proportion of Hindu population leads to a 3.024 kg per capita decrease in beef consumption. However, the negative relationship is weakened as society becomes more religiously heterogeneous, consistent with our theory. This result suggests that individuals living in societies that are more heterogeneous are less inclined to strictly follow religious norms. The Islam elasticity of GHG emissions from pork consumption is -4.062, which implies that a 1% increase in the proportion of Muslim population induces a 4.062% decrease in per capita GHG emissions from pork consumption. The Christianity elasticity of GHG emissions from pork consumption is negative, and the Buddhism elasticities of GHG emissions from two types of meat—beef and mutton/lamb—are negative.

This study is organized in the following manner. The conceptual framework is described in Section 2. Based on the framework, we outline the empirical model in Section 3 and describe the data in Section 4. We interpret the results from the estimation and calculate the elasticity based on the results in Section 5. Finally, we conclude in Section 6.

## 2. Conceptual Framework

We develop a conceptual framework linking religion to the equilibrium level of socially accepted and discouraged goods in static general equilibrium model (Figure 1). A household's concern with identity shaped in their religious belief affects their consumption decision between socially accepted and discouraged goods. The concern with religious identity evolves conditioned on the degree of religious homogeneity within the society to which the household belongs.

Figure 1. Conceptual Framework Linking Religion to the Equilibrium Level of Socially Accepted and Discouraged Goods under Static General Equilibrium Model



*Model*

Consider two households, $A$ and $B$, in a large, open economy. Household $A$ is endowed with $S_A$ units of land and $L_A$ units of labor, while household $B$ is endowed with $S_B$ units of land and $L_B$ units of labor. Wages, $w$, and rents, $r$, denote the prices of labor and land, respectively. The factor endowments are used in producing two final goods, $X$ and $Y$, by two firms, firm $X$ and firm $Y$. The competitive market prices of goods $X$ and $Y$ are denoted as $P_X$ and $P_Y$, respectively. We normalize $P_Y$ to 1 so that $P_X$ presents the relative price. Producing the goods contributes to air pollution. The pollution damage per unit of $X$ production and $Y$ production are denoted as $\theta_X$ and $\theta_Y$, respectively. Aggregate pollution emissions can be expressed as

(1) $$E \equiv \theta_X X + \theta_Y Y.$$

The market-clearing conditions for goods market and inputs (or factors) market are as follows:

(2.1) $$X^D = X_A + X_B = X^S \qquad Y^D = Y_A + Y_B = Y^S$$

(2.2) $$S^D = S_X + S_Y = S^S \qquad L^D = L_X + L_Y = L^S$$

*Households*

We apply a utility function that incorporates a household's concern with religious identity shaped by their religious belief following a framework suggested by Benjamin et al. (2010). Two households belong to a religious category $i$ for $i = \{a, b\}$, where $a$ is the religious category that household $A$ belongs to and $b$ is the religious category that household $B$ belongs to. Religion, with the existence of its prescriptions, often constrains a household's consumption decision between socially accepted and discouraged goods. The prescriptions indicate the religious norm (appropriate behavior) for a household to follow so that noncompliance to the prescriptions would evoke anxiety or discomfort in themselves and deteriorate their religious identity (Akerlof and Kranton, 2000). We assume that the religions that the two households believe in have different prescriptions on two goods, $X$ and $Y$. The prescription of household $A$'s religion considers good $X$ to be socially discouraged, while good $Y$ is socially accepted. In household $B$'s religion, the reverse is true.

The utility function of household $A$ is

(3) $$U_A = -\big(1 - W(h_a)\big)(X_A - X_0)^2 - W(h_a)(X_A - X_a)^2 + Y_A,$$

where $W(h_a)$ denotes the weight that household $A$ places on the norm for religious category $a$, $h_a$ is the degree of religious homogeneity, $X_0$ denotes household $A$'s preferred choice of the absence of identity concern, and $X_a$ denotes the choice prescribed for members of religious category $a$. The magnitude of the weight is dependent on the degree of religious homogeneity, $h_a$, within the society in which they live. We assume that $0 \leq W(h_a) \leq 1$, $W(0) = 0$, and $W_{h_a} > 0$. Deviation from the norm prescribed for household $A$'s religious group causes disutility that is increasing in $h_a$. Higher religious homogeneity causes the household's behavior to shift toward the category's norm. For example, a Hindu household residing in a religiously homogeneous town would be more concerned with their religious identity and would be more likely to avoid consuming beef than their counterparts residing in a religiously diverse town. Thus, the weight on the norm for religious category $a$ is an increasing function of the degree of religious homogeneity.

Household $A$ maximizes utility subject to the following budget constraint, $P_X X_A + Y_A \leq rS_A + wL_A$.[2] Given the quasilinear utility function, solving an unconstrained maximization problem yields the optimal consumption level of the socially discouraged good $X_A$:

(4) $$X_A^e = \underbrace{\big(1 - W(h_a)\big)X_0 + W(h_a)X_a}_{(a)} - P_X,$$

where the term $(a)$ represents a weighted average of the preferred action without identity concerns and the religious category norm. The larger the degree of religious homogeneity, $h_a$, the closer term $(a)$ is to $X_a$. Note that household $A$ would consume socially discouraged good $X$ only if the weighted average were greater than its price: There is a corner solution when $\big(1 - W(h_a)\big)X_0 + W(h_a)X_a \leq P_X$. Plugging this result into the budget constraint, we obtain the optimal consumption level of socially accepted good $Y_A$:

(5) $$Y_A^e = rS_A + wL_A - P_X X_A^e.$$

*Firms*

[2] Analogously, household $B$ chooses $Y_B$ to maximize $U_B = -\big(1 - W(h_b)\big)(Y_B - Y_0)^2 - W(h_b)(Y_B - Y_b)^2 + X_B$ subject to the budget constraint, $P_X X_B + Y_B \leq rS_B + wL_B$. Applying the same method used for household $A$'s problem, we derive the solutions for goods $X$ and $Y$ of household $B$: $Y_B^e = \big(1 - W(h_b)\big)Y_0 + W(h_b)Y_b - {}^1\!/_{P_X}$ and $X_B^e = (rS_B + wL_B - Y_B^e)\, {}^1\!/_{P_X}$.

Firm $X$ chooses the factor inputs to minimize costs subject to the following Cobb-Douglas production function $X = A_X S_X^{\beta} L_X^{1-\beta}$, where $A_X$ is total factor productivity and $\beta > 0$:[3]

(6) $$C^X = \min_{S_X, L_X} \{rS_X + wL_X\}.$$

Taking the first-order conditions with respect to each of the factor inputs, we obtain the conditional factor demands of firm $X$. Under perfect competition, the profit maximization condition, which states that the marginal cost of producing one unit of good $X$ is equal to its market price (i.e., $\frac{\partial C^X}{\partial X} = P^X$), holds:

(7) $$P_X = \left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta-1}\frac{r}{A_X} + \left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta}\frac{w}{A_X}.$$

The optimal consumption level of good $X$ for each household yields the equilibrium quantity of $X$:[4]

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[3] Similarly, firm $Y$ chooses its factor inputs subject to the Cobb-Douglas production function $Y = A_Y S_Y^{\beta} L_Y^{1-\beta}$, where $A_Y$ is total factor productivity: $C^Y = \min_{S_Y, L_Y}\{rS_Y + wL_Y\}$. Applying the same method as used for the problem for firm $X$, we drive the profit-maximization condition for firm $Y$: $1 = \left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta-1}\frac{r}{A_Y} + \left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta}\frac{w}{A_Y}$.

[4] We obtain the following solution for the vector of prices, $\left[P_X = \frac{A_Y}{A_X}\ P_X = 1\ w = \left(\frac{L^S}{S^S}\right)^{-\beta}(1-\beta)A_Y\ r = \left(\frac{L^S}{S^S}\right)^{1-\beta}\beta A_Y\right]'$, from the profit maximization conditions of both firms and market-clearing conditions (see Appendix A).

(8) $$X^e = X_A^e + X_B^e = X_0 - W(h_a)(X_0 - X_a) - \frac{A_Y}{A_X} + \left[\beta A_Y S_B \left(\frac{L^S}{S^S}\right)^{1-\beta} + (1-\beta) A_Y L_B \left(\frac{L^S}{S^S}\right)^{-\beta} - \left(Y_0 - W(h_b)(Y_0 - Y_b) - \frac{A_X}{A_Y}\right)\right]\frac{A_X}{A_Y}.$$

The weight that household $A$ places acts to decrease the equilibrium quantity of socially discouraged good $X^e$ such that $X_0 > X_a$ but increase the equilibrium quantity of the socially accepted good $Y^e$. It is reasonable to assume that $X_0$ is greater than $X_a$ since the religiously prescribed choice for good $X$ would mean low consumption of the good. Note that the equilibrium quantity $X^e$ also depends on the weight household $B$ places on good $Y$, which is considered to be socially discouraged such that $Y_0 > Y_b$. As the society to which household $B$ belongs is more religiously homogeneous, less of good $Y$ and more of good $X$ would be consumed. More formally, the impacts of $h_a$ and $h_b$ on $X^e$ are

(9) $$\frac{\partial X^e}{\partial h_a} = -\frac{\partial W(h_a)}{\partial h_a}(X_0 - X_a) < 0 \quad \frac{\partial X^e}{\partial h_b} = \frac{\partial W(h_b)}{\partial h_b}(Y_0 - Y_b)\frac{A_X}{A_Y} > 0.$$

In contrast, $h_a$ positively affects the equilibrium quantity $Y^e$, but the effect of $h_b$ is negative:

(10) $$\frac{\partial Y^e}{\partial h_a} = \frac{\partial W(h_a)}{\partial h_a}(X_0 - X_a)\frac{A_X}{A_Y} > 0 \quad \frac{\partial Y^e}{\partial h_b} = -\frac{\partial W(h_b)}{\partial h_b}(Y_0 - Y_b) < 0.$$

The degree of religious homogeneity of $h_i$ consequently contributes to aggregate pollution emissions through its impact on the quantity of $X$ and $Y$. A higher $h_a$ plays a role in reducing the aggregate emissions as it decreases the emissions from producing good $X$, but it has a countervailing effect on aggregate emissions as it causes emissions from producing good $Y$ to increase. On the contrary, a higher $h_b$ increases emissions from producing good $X$ but decreases emissions from producing good $Y$. The direction of change in $E^A$ is determined by the extent to which one's impact outweighs another:

(11) $$\frac{\partial E^A}{\partial h_a} = \underbrace{\frac{\partial E}{\partial X}\frac{\partial X^e}{\partial h_a}}_{(-)} + \underbrace{\frac{\partial E}{\partial Y}\frac{\partial Y^e}{\partial h_a}}_{(+)} \quad \frac{\partial E^A}{\partial h_b} = \underbrace{\frac{\partial E}{\partial X}\frac{\partial X^e}{\partial h_b}}_{(+)} + \underbrace{\frac{\partial E}{\partial Y}\frac{\partial Y^e}{\partial h_b}}_{(-)}.$$

The difference in emission intensities between the production systems of two goods, which imply the size of $\theta_X$ and $\theta_Y$ in equation (1), could be substantial. In the context of meat production systems, emission intensities significantly vary across the types of animals. According to Gerber et al. (2013), the emission intensity of cattle is approximately 46.2 kg $CO_2$ equivalent per kg of carcass weight (kg $CO_2$-eq/kg CW) in which emissions are mostly from enteric feed production and enteric fermentation. In the pork supply chain, emissions are mainly driven by feed production, and the emissions intensity for pig is approximately 6.1 kg $CO_2$-eq/kg CW. Thus, the emission intensities of two goods are also critical for assessing $E^A$.

## 3. Empirical Model

To identify the effect of religion on pollution emissions, we break the link into two stages. In the first stage, we conduct an estimation to measure the effect of religion on consumption of socially accepted and discouraged goods. Then, the parameters found through the estimation are combined with information on per unit pollution damage of production, emission intensities of the production systems of two goods. We build a reduced form equation to evaluate the first link between religion and consumption of socially accepted and discouraged goods, applying an approximation technique, log-linearization, on our solutions in equation (8) (see Appendix B). The empirical model linking the equilibrium quantity of the final goods to the degree of religious homogeneity is

(12) $$M_{j,n,t} = \boldsymbol{R'}_{\boldsymbol{i,n,t}}\boldsymbol{\pi_R} + \boldsymbol{R_{i,n,t}I'_{n,t}\pi_{RI}} + \pi_I I_{n,t} + \pi_S S_{n,t} + \pi_L L_{n,t} + \pi_A A_{n,t} + \vartheta_n + \delta_t + \varepsilon_{nt},$$

where $M_{j,n,t}$ indicates the equilibrium level of a good for $j = \{socially\ accepted\ good,\ discouraged\ good\}$ in country $n$ for year $t$; $\boldsymbol{R_{i,n,t}}$ is a vector of the share of religious group $i$ in country $n$ for year $t$; $I_{n,t}$ indicates an index of religious heterogeneity of country $n$ for year $t$; $S_{n,t}$ and $L_{n,t}$ measure the endowed land and endowed labor in country $n$ for year $t$, respectively; $A_{n,t}$ is a measure of the factor productivity in country $n$ for year $t$; $\vartheta_n$ is a country-specific effect; $\delta_t$ is a year-specific effect; $\varepsilon_{nt}$ is a random disturbance term; $\pi_I$, $\pi_S$, $\pi_L$, and $\pi_A$ are scalar coefficients; and $\boldsymbol{\pi_R}$ and $\boldsymbol{\pi_{RI}}$ are vector coefficients. The model yields following testable implications; 1) The effect of religion $i$ on the equilibrium level of two final goods depends on the degree of religious homogeneity. 2) An increase in the religious homogeneity raises the equilibrium level of a socially accepted good but lowers the equilibrium level of a socially discouraged good.

To obtain a measure of religious heterogeneity, we create an index, $I_{n,t}$, based on so-called "religious fractionalization." The index reflects the probability that two randomly selected individuals from a population belonged to different religious groups (Alesina et al., 2003). We compute the index as one minus the Herfindahl index of religious group shares following Alesina et al. (2003):

(13) $$I_{n,t} = 1 - \sum_{i=1}^{N} R_{i,n,t}^2,$$

where $R_{i,n,t}$ is the share of religious group $i$ ($i = 1 \ldots N$) in country $n$ for year $t$. The higher the $I_{n,t}$ is, the more a country is religiously fractionalized. Using the index, we identify an interaction term to allow the effect of the share of religious group $i$ to be conditional on the degree of religious heterogeneity. For religion $i$ that has a strict restrictive practice on good *j*—animal products in this context—the estimate $\boldsymbol{\pi_R}$ measuring the effect of the share of the religious group is expected to have a negative sign. However, the negative effect could be diminished conditional on the degree of religious heterogeneity given the existence of the interaction term. We therefore expect that the sign of the estimate $\boldsymbol{\pi_{RI}}$ would appear to be positive.

We estimate the marginal effects of the religion on consumption of socially accepted and discouraged goods using a two-way fixed-effects model. Our analysis is based on the fixed-effects approach due to its benefits in controlling unobservable site-specific effects such as topographical and meteorological features that undoubtedly affect livestock production as well as the influence of aggregate trend.[5] One issue is that our model may miss critical factors that cause omitted variable bias. We deal with this problem by introducing control variables—openness to trade, urbanization, and income—which have been found to be potential determinants of consumers' dietary choices toward livestock products and supply of the products in related studies (Rae, 1998; Steinfeld, 2007; York and Gossard, 2004). An estimation that includes a proxy for income growth (GDP growth) is conducted in an attempt to provide an additional robustness check. We also introduce a control variable to capture the extent of political stability that can affect both consumption and production.

[5] In addition to the fixed-effects model, we consider developing the seemingly unrelated regression (SUR) model since the error terms could be correlated across meat consumption equations. However, in the case in which the equations include identical regressors, the SUR estimator produces identical results to the equation-by-equation ordinary least square (OLS) estimator (Green, 2012).

*Effect of Religion on GHG*

We measure the religion elasticity of per capita GHG emissions from meat consumption, which indicates the extra carbon emissions per capita from meat consumption for a 1% increase in the proportion of a population believing in a particular religion. The religion elasticity of per capita GHG emissions from meat consumption is defined as $(\Delta GHG_j/GHG_j)/(\Delta Religion_i/Religion_i)$ for religion $i$ and meat $j$ evaluated at the means of the independent variables. The formula we use to compute the elasticity is

$$\frac{\partial GHG_j}{\partial Religion_i}\frac{\overline{Religion_i}}{\overline{GHG_j}} = \underbrace{\frac{\partial Meat_j}{\partial Religion_i}\frac{\overline{Religion_i}}{\overline{Meat_j}}}_{(b)}\underbrace{\frac{\partial GHG_j}{\partial Meat}}_{(c)}\frac{\overline{Meat_j}}{\overline{GHG_j}}, \quad (14)$$

where $GHG_j$ denotes per capita GHG emissions in the production process of $Meat_j$ and bar variables denote mean values.[6] Term (b) represents the religion elasticity of meat consumption calculated with the estimates $\boldsymbol{\pi_R}$ and $\boldsymbol{\pi_{RI}}$ from our regression at the means of the independent variables, and term (c) represents the average GHG emission intensity of our sample.

It is unlikely that the variables of interest—the share of population for each religion and the index of religious heterogeneity—are jointly determined with the dependent variable of meat consumption since the share of the religious population could be considered a stock. One structural shock that might affect both variables is major political violence such as ethnic war, revolutionary war, and adverse regime change. Such conflicts could mobilize people across a border and lead to a reduction in overall domestic production. To account for this potential

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[6] For example, Christianity elasticity of per capita GHG emissions from beef consumption at the sample mean is obtained as $\frac{\partial GHG}{\partial Christianity}\frac{\overline{Christianity}}{\overline{GHG}} = \frac{\partial Cattle}{\partial Christianity}\frac{\overline{Christianity}}{\overline{Cattle}}\frac{\partial GHG}{\partial Cattle}\frac{\overline{Cattle}}{\overline{GHG}}$.

endogeneity problem, we introduce a control variable that captures political instability and use a fixed-effects regression. For the total effect of religion on GHG emissions, we estimate the effect using two step-approaches by combining the emission intensity information after the first regression. By doing so, we can more clearly identify the effect of religion on GHG emissions as opposed to a reduced-form estimation between the two variables.

## 4. Data

We compile a unique panel dataset of 130 countries from 2002 to 2013. The most important variables in our analysis are measures of consumption for socially accepted and discouraged goods, measures of the share of religious group $i$ and religious heterogeneity (or homogeneity), and a measure of pollution damage per unit. To measure the effects of religious homogeneity and type of religion, we collect unique panel data from multiple sources on religion prevalence for four major religions: Association of Religion Data Archives, American Religious Identification Survey, Integrated Public Use Microdata Series International, Religions of the World, *A Comprehensive Encyclopedia of Beliefs and Practices*, World Religion Database, and national censuses. We then match these data with a panel dataset on meat consumption and emission intensity of meat from FAOSTAT. Table 2 presents the summary statistics, and Table 2A details the definitions of our data and sources.

The main measure of socially accepted and discouraged good consumption is consumption of four types of meat: beef, pork, chicken, and mutton/lamb. We manage the data for beef consumption, paying attention to details of Hindu dietary restrictions. It is known that Hinduism restricts beef consumption, but other bovine species are not necessarily forbidden to consume. Thus, it is critical not to mistakenly choose data mixed with other kinds of bovine meat to accurately measure the effect of Hinduism. We additionally use marine fish consumption in particular to see its relation to Christianity.

We calculate per capita consumption of meat using the dataset that consists of meat production and trade data. By doing so, we can account for two critical aspects. The first is that pollution is emitted in a production process so that the analysis on environmental impacts of the livestock sector should be based on production data. The second is that trade plays a growing role in the livestock sector in which meat products are strategically produced to export regardless of low domestic demand. India's exports of beef grew by 14% annually between 2000 and 2015, moving ahead of Brazil to become the world's largest beef exporter (Landes et al., 2016).

The measure of the share of a religious group is religion prevalence, which indicates the proportion of population believing in one of four major religions: Christianity, Buddhism, Islam, and Hinduism. For example, the religious prevalence in Indonesia as of the year 2005 was 8.9% Christian, 88.6% Muslim, 0.6% Buddhist, and 1.7% Hindu. The dataset on religious prevalence also provides detailed information on the prevalence of other religions, such as Judaism and indigenous religions. All other religious groups along with non-affiliated group in our dataset — categorized as "Others"— are used to create the index of religious heterogeneity $I_{n,t}$ according to equation (14). Of them, we incorporate the non-affiliated group to our empirical model as a control group, of which the average proportion is approximately 8.41% in our sample.

Table 3 highlights differences in religious prevalence and meat consumption across regions together with the index of religious heterogeneity. We assign countries to one of six regions, adopting a classification standard suggested by Marshall and Cole (2014): non-Muslim Africa (i.e., sub-Saharan countries), Muslim countries (i.e., countries in which Muslim confessional groups comprise 50% or more of the total population), (non-Muslim) South and

East Asia, Latin America, (non-Muslim) former Socialist countries, and North Atlantic countries.[7] The region with the highest average prevalence of Christianity is Latin America, followed by the North Atlantic countries. These two regions show the highest consumption of beef on average. Muslim countries, with an average Muslim population of 86.52%, on average show the least consumption of pork, 1.36 kg per capita. The North Atlantic countries consume the most pork. South and East Asia have the highest index of religious fractionalization, 0.426 on average, followed by non-Muslim Africa with 0.386.

[7] Appendix C lists the countries comprising each region.

Table 2. Summary Statistics

| Variable | Obs. | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| Beef | 1349 | 15.429 | 24.230 | 0.263 | 177.846 |
| Pork | 1089 | 18.878 | 28.562 | 0.000 | 249.044 |
| Chicken | 1297 | 16.586 | 13.162 | 0.439 | 91.651 |
| Mutton/lamb | 1172 | 2.609 | 5.247 | 0.000 | 48.918 |
| Fish | 1545 | 1.424 | 3.032 | 0.000 | 26.080 |
| Christianity | 1301 | 51.373 | 36.938 | 0.000 | 99.000 |
| Islam | 1301 | 28.049 | 37.458 | 0.000 | 99.650 |
| Buddhism | 1301 | 4.278 | 16.050 | 0.000 | 97.088 |
| Hinduism | 1301 | 1.951 | 10.322 | 0.000 | 81.300 |
| Others | 1301 | 14.349 | 15.833 | 0.000 | 81.529 |
| Non-affiliated | 1119 | 8.408 | 11.687 | 0.000 | 64.877 |
| Index | 1301 | 0.307 | 0.191 | 0.007 | 0.705 |
| Agricultural area | 1548 | 1.903 | 4.857 | 0.001 | 53.083 |
| Employment | 1561 | 57.174 | 11.146 | 29.510 | 85.627 |
| Agrisector growth | 1554 | 9.273 | 14.587 | -42.220 | 94.170 |
| Urbanization | 1561 | 57.056 | 22.310 | 12.253 | 100.000 |
| GDP growth | 1561 | 4.346 | 4.788 | -36.700 | 54.158 |
| FDI | 1547 | 5.092 | 7.634 | -16.071 | 89.476 |
| Stability | 1545 | -0.200 | 0.931 | -3.185 | 1.660 |
| | | | | | |
| Emission | | | | | |
| Beef | 1546 | 402.104 | 692.337 | 0.327 | 5938.760 |
| Chicken | 1534 | 9.524 | 13.132 | 0.000 | 136.478 |
| Pork | 1396 | 35.818 | 61.119 | 0.006 | 621.196 |
| Mutton/lamb | 1498 | 87.842 | 283.321 | 0.000 | 3115.372 |
| | | | | | |
| Emission Intensity | | | | | |
| Beef | 1546 | 36.220 | 31.222 | 0.159 | 249.137 |
| Chicken | 1534 | 1.519 | 1.649 | 0.000 | 23.185 |
| Pork | 1396 | 5.751 | 6.730 | 0.018 | 143.770 |
| Mutton/lamb | 1498 | 39.131 | 37.900 | 0.224 | 537.655 |

Table 3: Sample Means of Share of Religion Group (%), Index of Religious Heterogeneity & Meat Consumption (kg per capita) by Region

| | Religious Groups | | | | | | Meat Consumption | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Christianity | Islam | Buddhism | Hinduism | Others | Index | Beef | Pork | Chicken | Mutton/lamb |
| Non-Muslim Africa | 66.406 | 19.484 | 0.002 | 0.055 | 14.054 | 0.386 | 6.728 | 1.992 | 6.205 | 1.024 |
| (sub-Saharan countries) | (271) | (271) | (271) | (271) | (271) | (271) | (254) | (184) | (230) | (169) |
| Muslim countries | 7.258 | 86.521 | 0.741 | 1.347 | 4.134 | 0.208 | 5.882 | 1.356 | 16.497 | 3.964 |
| | (332) | (332) | (332) | (332) | (332) | (332) | (307) | (160) | (303) | (297) |
| South and East Asia | 24.766 | 3.075 | 35.076 | 11.587 | 25.497 | 0.426 | 25.525 | 13.593 | 15.192 | 7.442 |
| (non-Muslim) | (150) | (150) | (150) | (150) | (150) | (150) | (133) | (125) | (122) | (116) |
| Latin America | 87.321 | 0.486 | 0.055 | 1.564 | 10.575 | 0.197 | 26.469 | 9.287 | 23.885 | 0.385 |
| | (190) | (190) | (190) | (190) | (190) | (190) | (227) | (195) | (216) | (177) |
| Former Socialist countries | 74.901 | 7.083 | 0.042 | 0.006 | 17.969 | 0.314 | 10.708 | 25.835 | 16.566 | 1.184 |
| (non-Muslim) | (166) | (166) | (166) | (166) | (166) | (166) | (200) | (197) | (198) | (185) |
| North Atlantic countries | 75.110 | 3.219 | 0.225 | 0.217 | 21.229 | 0.377 | 25.838 | 52.523 | 19.090 | 2.516 |
| | (182) | (182) | (182) | (182) | (182) | (182) | (216) | (216) | (216) | (216) |

Note: Number of observations in parentheses.

The least religiously fractionalized region is Latin America at 0.197. The religious fractionalization index tends to increase over time. Restricting our attention to years with observations across regions, we find that the index increases by 0.006 from 2001 to 2011. The regions that lead to the average increment for the religious fractionalization index are former Socialist countries (with an increase of increase of 0.030) and North Atlantic countries (with an increase of 0.033). Interestingly, in non-Muslim Africa and Muslim countries, the trend appears to be going in the reverse direction. The religious fractionalization index decreases by 0.03 in non-Muslim Africa and by 0.004 in Muslim countries from 2001 to 2011. In non-Muslim Africa, Christianity is the most prevalent religion, and its share continues to increase. In Muslim countries, the share of Muslim population continues to increase by a small margin.

The measure of pollution damage per unit is GHG emissions intensity, which indicates the amount of GHG emissions (kg $CO_2$-eq) generated from the meat production process of one kilogram of carcass weight. The FAO evaluates emission intensities by considering four main categories of processing along the livestock supply chain: enteric fermentation, manure management, feed production, and energy consumption. In our sample, the average emission intensity for mutton/lamb is highest (39.13 kg $CO_2$-eq/kg CW), followed by beef (36.22 kg $CO_2$-eq/kg CW), which is far higher than the average emission intensities for chicken (1.52 kg $CO_2$-eq/kg CW) and pork (5.75 kg $CO_2$-eq/kg CW).[8]

[8] Ruminant animals such as cattle and goat produce enteric methane emissions through their digestive systems; these emissions account for 43% of emissions from beef production and 55% of emissions from small ruminants (FAO, 2013).

We use the ratio of employment to the population as a measure of endowed labor and agricultural area per capita as a measure of endowed land, both from the World Bank (WB) database. Factor productivity is measured by the growth rate of investment in agriculture, forestry, and fishing from FAO, which could induce technological progress in the agricultural sector. Control variables, trade openness, urbanization, GDP growth rate, and political stability—which are highly likely to influence meat consumption—are collected from the WB database.

**5. Results**

We present three sets of fixed-effects regressions on consumption of four types of meat with and without year dummies to estimate equation (12). The first specification is our baseline model, which follows from the reduced equation (12). We include more control variables in the second through third specifications to check consistency in empirical inferences. As additional robustness checks, we present random-effects regressions in Table 1A.

Tables 4 to 7 present the estimation results measuring the marginal effect of the religious homogeneity and type of religion on meat consumption. The coefficient estimates from the fixed-effects models are consistent in terms of sign and magnitude, regardless of the existence of year dummies. In Table 4, we find that the effect of Hinduism on beef consumption is negative and significant across all specifications. Consistent with our theory, an interaction term between Hinduism and the religious fractionalization index displays a positive and significant coefficient estimate. This result suggests that the negative effect of Hinduism on beef consumption diminishes as a society becomes more religiously heterogeneous. At the sample mean of the index, the marginal effect of Hinduism on beef consumption is -3.024 kilograms per capita (kg per capita),[9] which implies that one-unit increase in the proportion of Hindu population lowers beef consumption by 3.024 kg per capita. At one standard deviation above the mean of the index, the effect equals -2.499 kg per capita[10]. We also find that Islam and Buddhism are negatively associated with beef consumption. A one-unit increase in the proportion of Muslim and Buddhist populations decreases beef consumption by 0.790–1.025 kg per capita, and 2.732–3.121 kg per capita, respectively.

[9] $-3.024 = -3.870 + 2.753 * 0.307$, where 0.307 is the sample mean of the index.

[10] $-2.499 = -3.870 + 2.753 * 0.498$, where 0.498 is one standard deviation above the mean of the index.

Note: The calculation is based on the specification (3) Table 4.

Table 4. Determinants of Beef Consumption, 2002-2013, Fixed Effects Model

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Christianity | -0.322 | -0.383 | -0.464 | -0.311 | -0.421 | -0.487 |
| | (0.412) | (0.399) | (0.404) | (0.414) | (0.411) | (0.412) |
| Christianity*Index | 0.634 | 0.635 | 0.755 | 0.647 | 0.690 | 0.790 |
| | (0.525) | (0.515) | (0.524) | (0.524) | (0.522) | (0.527) |
| Islam | -0.853** | -0.790* | -0.893** | -0.809* | -0.956** | -1.025** |
| | (0.421) | (0.407) | (0.417) | (0.425) | (0.426) | (0.425) |
| Islam*Index | 0.677 | 0.737 | 0.796 | 0.678 | 0.686 | 0.735 |
| | (0.588) | (0.570) | (0.571) | (0.581) | (0.574) | (0.572) |
| Buddhism | -2.781*** | -3.121*** | -3.029*** | -2.732*** | -2.960*** | -2.913*** |
| | (0.655) | (0.660) | (0.640) | (0.657) | (0.662) | (0.637) |
| Buddhism*Index | -0.520 | -1.675** | -1.257* | -0.465 | -0.927 | -0.744 |
| | (0.634) | (0.686) | (0.712) | (0.634) | (0.669) | (0.690) |
| Hinduism | -4.034*** | -3.963*** | -3.870*** | -4.080*** | -3.927*** | -3.810*** |
| | (1.009) | (1.007) | (0.980) | (0.987) | (0.991) | (0.952) |
| Hinduism*Index | 2.349 | 2.926* | 2.753* | 2.483* | 2.335 | 2.285 |
| | (1.487) | (1.525) | (1.499) | (1.413) | (1.436) | (1.398) |
| Non-affiliated | -0.471 | -0.493 | -0.549 | -0.460 | -0.581 | -0.608 |
| | (0.579) | (0.570) | (0.570) | (0.580) | (0.580) | (0.576) |
| Non-affiliated*Index | 0.334 | 0.346 | 0.431 | 0.335 | 0.392 | 0.456 |
| | (1.135) | (1.124) | (1.122) | (1.137) | (1.138) | (1.132) |
| Agricultural area | 0.212 | 0.334** | 0.343*** | 0.186 | 0.338** | 0.342*** |
| | (0.143) | (0.131) | (0.129) | (0.138) | (0.134) | (0.130) |
| Employment | 0.305*** | 0.329*** | 0.316*** | 0.314*** | 0.311*** | 0.301*** |
| | (0.077) | (0.077) | (0.074) | (0.079) | (0.079) | (0.076) |
| Agrisector growth | 0.006 | 0.007 | 0.003 | 0.006 | 0.006 | -0.0007 |
| | (0.007) | (0.007) | (0.007) | (0.007) | (0.007) | (0.007) |
| Index | -65.45 | -66.60 | -77.95 | -65.38 | -72.65 | -81.82 |
| | (65.19) | (63.36) | (63.72) | (65.38) | (64.81) | (64.61) |
| Urbanization | | 0.336*** | 0.311*** | | 0.183*** | 0.191*** |
| | | (0.078) | (0.083) | | (0.051) | (0.053) |
| FDI | | -0.005 | -0.004 | | -0.006 | -0.006 |
| | | (0.010) | (0.011) | | (0.011) | (0.011) |
| GDP growth | | | 0.059* | | | 0.070** |
| | | | (0.033) | | | (0.028) |
| Stability | | | 0.084 | | | -0.032 |
| | | | (0.329) | | | (0.307) |
| Country dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Year dummy | Yes | Yes | Yes | No | No | No |
| N | 1119 | 1109 | 1099 | 1119 | 1109 | 1099 |
| adj. $R^2$ | 0.988 | 0.988 | 0.988 | 0.988 | 0.988 | 0.988 |

Notes: Robust standard errors in parentheses. * p<0.1 ** p<0.05 *** p<0.01

Table 5. Determinants of Pork Consumption, 2002-2013, Fixed Effects Model

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Christianity | -1.378*** | -1.396*** | -1.383*** | -1.244*** | -1.368*** | -1.354*** |
| | (0.455) | (0.452) | (0.459) | (0.458) | (0.465) | (0.474) |
| Christianity*Index | 0.744 | 0.788 | 0.728 | 0.673 | 0.829 | 0.768 |
| | (0.723) | (0.724) | (0.742) | (0.751) | (0.744) | (0.764) |
| Islam | -2.381*** | -2.388*** | -2.373*** | -1.914*** | -2.080*** | -2.079*** |
| | (0.522) | (0.514) | (0.511) | (0.512) | (0.522) | (0.523) |
| Islam*Index | 0.389 | 0.448 | 0.402 | 0.577 | 0.706 | 0.654 |
| | (0.714) | (0.720) | (0.739) | (0.748) | (0.739) | (0.758) |
| Buddhism | -2.038** | -1.949** | -1.915** | -2.120** | -2.182** | -2.175** |
| | (0.896) | (0.916) | (0.916) | (0.879) | (0.904) | (0.900) |
| Buddhism*Index | 0.787 | 0.712 | 0.686 | 0.744 | -0.247 | -0.324 |
| | (0.957) | (1.015) | (1.149) | (1.031) | (0.951) | (1.088) |
| Hinduism | -1.069 | -0.972 | -0.972 | -2.145** | -1.161 | -1.151 |
| | (0.898) | (0.856) | (0.860) | (0.833) | (0.829) | (0.829) |
| Hinduism*Index | 0.638 | 0.866 | 0.866 | 2.126* | 1.902 | 1.869 |
| | (1.257) | (1.292) | (1.301) | (1.147) | (1.188) | (1.198) |
| Non-affiliated | -0.587 | -0.603 | -0.571 | -0.311 | -0.509 | -0.481 |
| | (0.567) | (0.568) | (0.575) | (0.584) | (0.584) | (0.592) |
| Non-affiliated*Index | -0.0904 | -0.041 | -0.114 | -0.319 | -0.055 | -0.121 |
| | (1.092) | (1.096) | (1.111) | (1.133) | (1.132) | (1.149) |
| Agricultural area | 0.545** | 0.638** | 0.661** | 0.074 | 0.410* | 0.422* |
| | (0.266) | (0.276) | (0.280) | (0.222) | (0.236) | (0.240) |
| Employment | 0.173*** | 0.181*** | 0.184*** | 0.228*** | 0.224*** | 0.225*** |
| | (0.050) | (0.050) | (0.050) | (0.047) | (0.048) | (0.047) |
| Agrisector growth | -0.008 | -0.008 | -0.008 | -0.001 | -0.0007 | -0.0005 |
| | (0.007) | (0.007) | (0.007) | (0.007) | (0.007) | (0.007) |
| Index | -142.2* | -146.5* | -141.4* | -128.3 | -145.8* | -140.8* |
| | (77.92) | (77.64) | (79.31) | (79.92) | (79.64) | (81.53) |
| Urbanization | | 0.040 | 0.037 | | 0.236*** | 0.230*** |
| | | (0.090) | (0.092) | | (0.059) | (0.061) |
| FDI | | -0.038** | -0.039** | | -0.033* | -0.034* |
| | | (0.018) | (0.018) | | (0.018) | (0.018) |
| GDP growth | | | -0.008 | | | -0.003 |
| | | | (0.021) | | | (0.023) |
| Stability | | | -0.025 | | | -0.087 |
| | | | (0.313) | | | (0.329) |
| Country dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Year dummy | Yes | Yes | Yes | No | No | No |
| N | 901 | 901 | 891 | 901 | 901 | 891 |
| adj. $R^2$ | 0.993 | 0.993 | 0.993 | 0.993 | 0.993 | 0.993 |

Notes: Robust standard errors in parentheses. * p<0.1 ** p<0.05 *** p<0.01

Table 6. Determinants of Chicken Consumption, 2002-2013, Fixed Effects Model

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Christianity | 0.756 | 0.764 | 0.609 | 1.187*** | 0.897* | 0.809* |
| | (0.474) | (0.480) | (0.481) | (0.448) | (0.461) | (0.467) |
| Christianity*Index | -1.279** | -1.271** | -1.050* | -1.200** | -1.195** | -1.059* |
| | (0.603) | (0.612) | (0.614) | (0.532) | (0.546) | (0.546) |
| Islam | 0.240 | 0.184 | 0.169 | 1.556*** | 1.221** | 1.313** |
| | (0.537) | (0.549) | (0.540) | (0.523) | (0.521) | (0.523) |
| Islam*Index | -1.933** | -1.982** | -1.833** | -0.825 | -0.963 | -0.815 |
| | (0.766) | (0.779) | (0.761) | (0.695) | (0.738) | (0.727) |
| Buddhism | -1.245 | -0.998 | -0.491 | -0.921 | -2.574** | -2.159* |
| | (1.080) | (1.116) | (1.110) | (1.043) | (1.081) | (1.103) |
| Buddhism*Index | -0.745 | -0.0870 | 1.503 | -0.961 | -4.730*** | -3.444** |
| | (1.462) | (1.635) | (1.738) | (1.324) | (1.457) | (1.575) |
| Hinduism | 0.611 | 0.518 | 0.706 | -3.079** | -0.926 | -0.869 |
| | (1.454) | (1.459) | (1.449) | (1.352) | (1.409) | (1.408) |
| Hinduism*Index | -8.962*** | -9.033*** | -9.378*** | -1.544 | -4.291** | -4.475** |
| | (2.122) | (2.144) | (2.140) | (2.059) | (2.060) | (2.058) |
| Non-affiliated | 0.978** | 0.969* | 0.869* | 1.842*** | 1.441*** | 1.350*** |
| | (0.494) | (0.498) | (0.495) | (0.466) | (0.461) | (0.460) |
| Non-affiliated*Index | -3.318*** | -3.288*** | -3.157*** | -3.695*** | -3.548*** | -3.439*** |
| | (0.991) | (1.000) | (0.989) | (0.942) | (0.939) | (0.935) |
| Agricultural area | -1.600*** | -1.555*** | -1.390** | -3.539*** | -2.838*** | -2.655*** |
| | (0.577) | (0.575) | (0.578) | (0.616) | (0.612) | (0.634) |
| Employment | 0.064 | 0.056 | 0.051 | 0.261*** | 0.220*** | 0.231*** |
| | (0.081) | (0.082) | (0.081) | (0.080) | (0.077) | (0.077) |
| Agrisector growth | -0.0004 | -0.0008 | -0.001 | -0.002 | -0.001 | 0.008 |
| | (0.009) | (0.009) | (0.010) | (0.007) | (0.007) | (0.008) |
| Index | 170.2** | 168.5** | 147.8** | 190.1*** | 180.6*** | 167.8** |
| | (71.44) | (72.33) | (72.12) | (66.35) | (67.50) | (67.47) |
| Urbanization | | -0.130 | -0.114 | | 0.776*** | 0.796*** |
| | | (0.140) | (0.138) | | (0.087) | (0.090) |
| FDI | | -0.010 | -0.003 | | -0.018 | -0.005 |
| | | (0.022) | (0.023) | | (0.022) | (0.023) |
| GDP growth | | | 0.019 | | | -0.077* |
| | | | (0.042) | | | (0.042) |
| Stability | | | 1.638*** | | | 1.627*** |
| | | | (0.473) | | | (0.510) |
| Country dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Year dummy | Yes | Yes | Yes | No | No | No |
| N | 1078 | 1078 | 1068 | 1078 | 1078 | 1068 |
| adj. $R^2$ | 0.945 | 0.945 | 0.946 | 0.933 | 0.938 | 0.939 |

Notes: Robust standard errors in parentheses. * p<0.1 ** p<0.05 *** p<0.01

Table 7. Determinants of Mutton/Lamb Consumption, 2002-2013, Fixed Effects Model

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Christianity | 0.256 | 0.257 | 0.227 | 0.215 | 0.213 | 0.184 |
| | (0.238) | (0.239) | (0.238) | (0.231) | (0.230) | (0.227) |
| Christianity*Index | -0.195 | -0.214 | -0.169 | -0.146 | -0.143 | -0.100 |
| | (0.234) | (0.241) | (0.239) | (0.225) | (0.225) | (0.221) |
| Islam | 0.307 | 0.342 | 0.341 | 0.238 | 0.235 | 0.250 |
| | (0.277) | (0.289) | (0.287) | (0.264) | (0.264) | (0.261) |
| Islam*Index | -0.150 | -0.141 | -0.122 | -0.140 | -0.139 | -0.117 |
| | (0.265) | (0.263) | (0.259) | (0.261) | (0.261) | (0.256) |
| Buddhism | -1.434*** | -1.500*** | -1.381*** | -1.446*** | -1.451*** | -1.325*** |
| | (0.316) | (0.318) | (0.324) | (0.316) | (0.317) | (0.321) |
| Buddhism*Index | -1.057** | -1.319** | -0.974* | -0.961** | -0.968** | -0.636 |
| | (0.469) | (0.576) | (0.590) | (0.465) | (0.488) | (0.491) |
| Hinduism | -1.470*** | -1.476*** | -1.401*** | -1.472*** | -1.476*** | -1.390*** |
| | (0.401) | (0.407) | (0.404) | (0.392) | (0.396) | (0.393) |
| Hinduism*Index | -0.911 | -0.783 | -0.908 | -0.958 | -0.950 | -1.056 |
| | (0.740) | (0.727) | (0.722) | (0.736) | (0.742) | (0.734) |
| Non-affiliated | 0.484 | 0.495 | 0.489 | 0.417 | 0.414 | 0.419 |
| | (0.399) | (0.403) | (0.400) | (0.387) | (0.385) | (0.382) |
| Non-affiliated*Index | -1.256 | -1.278 | -1.276 | -1.167 | -1.163 | -1.176 |
| | (0.887) | (0.896) | (0.890) | (0.873) | (0.873) | (0.865) |
| Agricultural area | -0.432 | -0.439 | -0.407 | -0.372 | -0.373 | -0.350 |
| | (0.291) | (0.286) | (0.290) | (0.282) | (0.281) | (0.285) |
| Employment | 0.040** | 0.044*** | 0.039** | 0.042** | 0.043** | 0.038** |
| | (0.016) | (0.016) | (0.017) | (0.016) | (0.017) | (0.017) |
| Agrisector growth | -0.011** | -0.011** | -0.012** | -0.008** | -0.008** | -0.010** |
| | (0.004) | (0.004) | (0.005) | (0.004) | (0.004) | (0.004) |
| Index | 39.83 | 41.77 | 37.84 | 33.74 | 33.46 | 30.03 |
| | (37.16) | (37.91) | (37.54) | (36.11) | (36.13) | (35.51) |
| Urbanization | | 0.061 | 0.058 | | 0.002 | 0.010 |
| | | (0.038) | (0.039) | | (0.020) | (0.020) |
| FDI | | -0.006 | -0.005 | | -0.002 | -0.002 |
| | | (0.006) | (0.005) | | (0.005) | (0.005) |
| GDP growth | | | 0.008 | | | 0.012 |
| | | | (0.013) | | | (0.011) |
| Stability | | | 0.316** | | | 0.351*** |
| | | | (0.123) | | | (0.120) |
| Country dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Year dummy | Yes | Yes | Yes | No | No | No |
| N | 970 | 970 | 960 | 970 | 970 | 960 |
| adj. $R^2$ | 0.963 | 0.963 | 0.963 | 0.963 | 0.963 | 0.963 |

Notes: Robust standard errors in parentheses. * p<0.1 ** p<0.05 *** p<0.01

We find that although Islam has an independent effect on pork consumption, the negative effect is not conditioned on the society's degree of religious heterogeneity (Table 5).[11] The insignificant results of the interaction term could indicate that Muslims stick to their religious practices regardless of the characteristics of their community or be a sign of lower tolerance of violating religious practices. Christianity has a strong and significantly negative relationship with pork consumption, but the negative effect is not conditioned on the society's degree of religious heterogeneity.

The independent effects of religions on chicken and mutton/lamb consumption (Tables 6 and 7, respectively) do not show interpretable patterns across specifications. This may be because those two types of meat are not restricted by religious dietary laws. A similar consequence occurs with Christianity, which does not impose a strict practice on diet. Christianity is positively associated with chicken but negatively associated with pork. It has no significant impact on the consumption of beef or mutton/lamb. However, we find that for the non- religiously affiliated group, the decreasing rate of chicken consumption is higher as a community becomes more religiously heterogenous, compared to Christianity and Islam. We note that two religions, Buddhism and Hinduism, have a negative relationship with consumption of almost all types of meat. Such results possibly reflect that Buddhist and Hindu cultures encourage a vegetarian diet.

[11] We separately conduct estimations of pork consumption for Muslim countries, and South and East Asia to see if there exist regional differences in the effects of Islam. The estimation results are available upon request.

We find that Christianity has no direct effect on fish consumption (Table 8). It is interesting to note that the interaction term between Christianity and the fractionalization index displays a positive sign. It indicates that as a society becomes more religiously heterogeneous, fish consumption by Christian population increases. We find that the similar results appear to both Muslim and non-religiously affiliated groups, but the reverse takes place to the Hindu group. A possible explanation is the case in which individuals belong to the religious groups that encourage fish consumption but reside in countries where access to fishery products is relatively limited by geography. They may tend to consume more fish foods when they emigrate to countries where fishery products are more accessible, but the religious heterogeneity of the country happens to be relatively higher.

Table 8. Determinants of Fish Consumption, 2002-2013, Fixed Effects Model

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Christianity | -0.005 | -0.008 | -0.009 | -0.00906 | -0.00527 | -0.00741 |
| | (0.096) | (0.095) | (0.094) | (0.0952) | (0.0947) | (0.0929) |
| Christianity*Index | 0.547*** | 0.562*** | 0.569*** | 0.545*** | 0.558*** | 0.568*** |
| | (0.147) | (0.146) | (0.143) | (0.147) | (0.145) | (0.143) |
| Islam | 0.089 | 0.079 | 0.092 | 0.0724 | 0.0861 | 0.0901 |
| | (0.109) | (0.110) | (0.109) | (0.111) | (0.107) | (0.106) |
| Islam*Index | 0.593*** | 0.607*** | 0.618*** | 0.573*** | 0.591*** | 0.601*** |
| | (0.161) | (0.160) | (0.160) | (0.161) | (0.159) | (0.159) |
| Buddhism | -0.775** | -0.741** | -0.730** | -0.768** | -0.734** | -0.718** |
| | (0.367) | (0.357) | (0.358) | (0.369) | (0.356) | (0.356) |
| Buddhism*Index | 0.203 | 0.299 | 0.345 | 0.218 | 0.284 | 0.351 |
| | (0.647) | (0.636) | (0.638) | (0.648) | (0.641) | (0.645) |
| Hinduism | 0.733 | 0.751 | 0.744 | 0.759 | 0.768 | 0.764 |
| | (0.647) | (0.650) | (0.650) | (0.649) | (0.652) | (0.653) |
| Hinduism*Index | -2.247* | -2.315* | -2.305* | -2.303* | -2.309* | -2.320* |
| | (1.304) | (1.304) | (1.300) | (1.318) | (1.318) | (1.319) |
| Non-affiliated | -0.202* | -0.196* | -0.197* | -0.208* | -0.190* | -0.194* |
| | (0.115) | (0.114) | (0.113) | (0.116) | (0.114) | (0.113) |
| Non-affiliated*Index | 0.792*** | 0.754*** | 0.756*** | 0.791*** | 0.749*** | 0.754*** |
| | (0.281) | (0.281) | (0.279) | (0.281) | (0.281) | (0.279) |
| Agricultural area | -0.051 | -0.049 | -0.055 | -0.039 | -0.052 | -0.056 |
| | (0.044) | (0.048) | (0.048) | (0.037) | (0.047) | (0.047) |
| Employment | -0.012 | -0.010 | -0.009 | -0.019 | -0.015 | -0.014 |
| | (0.017) | (0.017) | (0.017) | (0.015) | (0.015) | (0.015) |
| Agrisector growth | -0.003* | -0.002 | -0.002 | -0.002 | -0.002 | -0.002 |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) |
| Index | -44.28*** | -45.20*** | -45.53*** | -44.29*** | -44.78*** | -45.36*** |
| | (15.24) | (15.11) | (14.86) | (15.27) | (15.05) | (14.80) |
| Urbanization | | -0.016 | -0.009 | | -0.014 | -0.013 |
| | | (0.029) | (0.029) | | (0.023) | (0.023) |
| FDI | | 0.003 | 0.003 | | 0.003 | 0.003 |
| | | (0.004) | (0.004) | | (0.004) | (0.004) |
| GDP growth | | | -0.007 | | | -0.004 |
| | | | (0.006) | | | (0.006) |
| Stability | | | 0.121 | | | 0.108 |
| | | | (0.091) | | | (0.087) |
| Country dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Year dummy | Yes | Yes | Yes | No | No | No |
| N | 1282 | 1270 | 1260 | 1282 | 1270 | 1260 |
| adj. $R^2$ | 0.923 | 0.925 | 0.925 | 0.924 | 0.925 | 0.925 |

Notes: Robust standard errors in parentheses. * p<0.1 ** p<0.05 *** p<0.01

*Religion Elasticity of GHG Emissions*

Table 9 summarizes the religion elasticity of GHG emission by meat and religion. The Islam elasticities of GHG emissions from beef consumption and pork consumption are -1.147 and -4.062, respectively, implying that a 1% increase in the proportion of Muslim population induces a 1.147% decrease in per capita GHG emissions from beef consumption and a 4.062% decrease from pork consumption, respectively. The effect of Christianity on GHG emissions from pork consumption is negative and highly elastic. The Buddhism and Hinduism elasticities of GHG emissions from beef and mutton/lamb consumption are all negative.

Table 9. Religion Elasticity of GHG Emissions (kg $CO_2$-eq per capita) from Meat Consumption

| | (1)<br>GHG from beef | (2)<br>GHG from pork | (3)<br>GHG from chicken | (4)<br>GHG from mutton/lamb |
|---|---|---|---|---|
| Christianity | -0.907 | -7.728*** | 1.974 | 2.417 |
| | 1.059 | 1.834 | 2.352 | 2.081 |
| Islam | -1.147** | -4.062*** | -1.178 | 2.037 |
| | 0.540 | 0.819 | 1.570 | 1.253 |
| Buddhism | -0.996*** | -0.716 | -0.017 | -1.504*** |
| | 0.197 | 0.433 | 0.732 | 0.392 |
| Hinduism | -0.480*** | -0.136 | -0.423** | -1.131*** |
| | 0.103 | 0.136 | 0.209 | 0.261 |

Notes: Standard errors in parentheses. ** $p<0.05$ *** $p<0.01$

The significance of the results is interesting from a policy standpoint since this will allow us to assess how changes in a society's religious landscape would affect GHG emissions from livestock sectors. Stonawski et al. (2015) project that between 2010 and 2050, the share of Muslim population will rise from 23.2% to 29.7% and the share of Buddhist population will decline from 7.1% to 5.2%. We calculate the average annual growth rate of the share of each religion under an assumption that the share of each religion changes by the same rate between

2010 and 2050. We expect that GHG emissions from beef and pork production decreases by 0.711% and 2.518%, respectively, according to the annual change in the share of the Muslim population. In addition, the decrease in the share of Buddhist population would lead to an increase in GHG emissions from beef production by 0.777% and in GHG emissions from mutton/lamb production by 1.173%.

## 6. Summary and Conclusion

This study examines the link between religion and individuals' consumption decisions over livestock products and how this link consequently affects GHG emissions. We theoretically model how religion and the religious homogeneity of a surrounding society influence households to make consumption decisions between socially accepted and discouraged goods. Our theoretical model predicts that an increase in religious homogeneity within a society leads to an increase in the equilibrium quantity of a socially accepted good but a decrease in the equilibrium quantity of a socially discouraged good. The equilibrium quantity of a good is determined by one household's weight on the socially accepted good and another household's weight on the same good, which it considers socially discouraged. Finally, producing the good in the equilibrium quantity contributes to GHG emissions.

To test the theoretical results, we estimate the effect of religion on meat consumption and assess how the effect is conditioned on the degree of religious homogeneity within a society using a two-way fixed-effects model. The estimation results are applied to calculate the religion elasticity of GHG emissions from meat consumption. We find that the negative effect of Hinduism on beef is conditioned on the society's degree of religious heterogeneity. A one-unit increase in the proportion of Hindu population leads to a 3.024 kg per capita decrease in beef consumption at the sample mean of our religious fractionalization index. At one standard deviation above the mean, the effect equals -2.499 kg per capita. We also find that the Islam elasticity of GHG emissions from pork consumption is -4.062, indicating that a 1% increase in the proportion of Muslim population induces a 4.062% decrease in per capita GHG emissions from pork consumption. Our results indicate that the effects of religion on individuals' dietary choices in religious belief vary considerably from religion to religion, and the impacts could be conditioned on a social setting faced.

The International Organization for Migration (IOM, 2017) reports that the number of international migrants continues to grow, which are mainly attributed to asylum applications and labor migration. The flows of labor migration are mostly from lower-income countries to countries which have labor shortages and offer higher wage opportunities such as from Africa to Western Europe. Immigrants and ethnic minorities might try to maintain their own dietary habits not to deteriorate their identity after immigration (Levenstein, 1985). However, mixed food habits could take place amongst younger people in the second and third generations due to adoption of a Western lifestyle (Gilbert and Khokhar, 2008). We thus expect that the communities with the number of new international migrants would face new demand of livestock products in types and quality that migrants consume and, accordingly, GHG emissions from the livestock sector, but the phenomenon will gradually disappear as the young and the next generation immigrants adapt their dietary habits to their Western food and cultural environment.

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**Appendices**

Appendix A. Derivation for the Vector Prices

Firm $X$ chooses the factor inputs to minimize costs subject to the Cobb-Douglas production function $X = A_X S_X^{\beta} L_X^{1-\beta}$, where $A_X$ is total factor productivity and $\beta > 0$:

(A1.1) $$C^X = \min_{S_X, L_X} \{rS_X + wL_X\}.$$

Rearrange the production function in terms of $L_X$, then $L_X = \left(\frac{1}{A_X} X S_X^{-\beta}\right)^{\frac{1}{1-\beta}}$. The unconstrained problem is

(A1.2) $$\min_{S_X} rS_X + w\left(\frac{1}{A_X} X S_X^{-\beta}\right)^{\frac{1}{1-\beta}} .$$

The first-order condition is

(A1.3) $$\left(\frac{\beta}{1-\beta}\right) w \left(\frac{X}{A_X}\right)^{\frac{1}{1-\beta}} S_X{}^{\frac{-1}{1-\beta}} = r.$$

We rearrange equation (A1.3) in terms of $S_X = \left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta-1}\left(\frac{X}{A_X}\right)$ and obtain $L_X = \left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta}\frac{X}{A_X}$ using the production function. Then the objective function is now

(A1.4) $$C_X = r\left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta-1}\frac{X}{A_X} + w\left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta}\frac{X}{A_X}.$$

Under perfect competition, $\frac{\partial C^X}{\partial X} = P^X$, which states that the marginal cost of producing one unit of the good $X$ is equal to its market price, holds:

(A1.5) $$P_X = \left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta-1}\frac{R}{A_X} + \left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta}\frac{w}{A_X}.$$

Similarly, firm $Y$ chooses its factor inputs subject to the Cobb-Douglas production function $Y = A_Y S_Y^{\beta} L_Y^{1-\beta}$, where $A_Y$ is total factor productivity:

(A1.6) $$C^Y = \min_{S_Y, L_Y} rS_Y + wL_Y.$$

Taking the same steps, we obtain $S_Y = \left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta-1}\frac{Y}{A_Y}$ and $L_Y = \left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta}\frac{Y}{A_Y}$. The objective function of the firm $Y$ is now

(A1.7) $$C_Y = r\left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta-1}\frac{Y}{A_Y} + w\left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta}\frac{Y}{A_Y}.$$

Applying the same method as used for the problem for the firm $X$, we drive the following profit maximization condition for the firm $Y$:

(A1.8) $$1 = \left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta-1}\frac{r}{A_Y} + \left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta}\frac{w}{A_Y}.$$

We plug equation (A1.8) into equation (A1.5) to find the price of good $X$ and get a solution for $P_X$:

(A1.9) $$P_X = \frac{A_Y}{A_X}.$$

Using the market-clearing condition for labor and land gives us

(A1.10) $$L^S = L_X + L_Y = \left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta}\frac{X}{A_X} + \left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta}\frac{Y}{A_Y}$$

(A1.11) $$S^S = S_X + S_Y = \left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta-1}\frac{X}{A_X} + \left(\frac{1-\beta}{\beta}\frac{r}{w}\right)^{\beta-1}\frac{Y}{A_Y}.$$

Taking the ratio between equations (A1.10) and (A1.11), we find the relationship between the prices of factor inputs:

(A1.12) $$\frac{L^S}{S^S}\left(\frac{1-\beta}{\beta}\right)w = r.$$

Plugging equation (A1.12) into equation (A1.8) yields the factor price of labor:

(A1.13) $$w = \left(\frac{L^S}{S^S}\right)^{-\beta}(1-\beta)A_Y,$$

which we plug back into equation (A1.12) to obtain the price of land:

(A1.14) $$r = \left(\frac{L^S}{S^S}\right)^{1-\beta}\beta A_Y.$$

Then, we obtain the following solution for the vector of prices, $\left[P_X = \frac{A_Y}{A_X}\; P_X = 1\; w = \left(\frac{L^S}{S^S}\right)^{-\beta} (1-\beta)A_Y\; r = \left(\frac{L^S}{S^S}\right)^{1-\beta} \beta A_Y\right]'$. Plugging the solution to the problem of optimal consumption level of good $Y$ for each household yields the equilibrium produced quantity of $Y$:

(A1. 15)
$$Y^e = Y_A^e + Y_B^e = \beta A_Y S_A \left(\frac{L^S}{S^S}\right)^{1-\beta} + (1-\beta)A_Y L_A \left(\frac{L^S}{S^S}\right)^{-\beta}$$
$$-\left[X_0 - W(h_a)(X_0 - X_a) - \frac{A_Y}{A_X}\right]\frac{A_X}{A_Y} + Y_0 - W(h_b)(Y_0 - Y_b) - \frac{A_X}{A_Y}.$$

Appendix B. Derivation for the Reduced Form

For simplicity's sake, we add a few more assumptions: 1) the aggregate endowment of labor is equivalent to the aggregate endowment of land (i.e., $\frac{L^S}{S^S} = 1$); 2) the ratio of the factor productivities is constant (i.e., $\frac{A_X}{A_Y} = \alpha$); and 3) both household $A$'s preferred choice of the absence of identity concern $X_0$ and the choice prescribed for members of the religious category $i$ $X_i$ are consistent over time.

The simplified solutions for two goods are

(A2.1) $$X^e = \gamma_0 - (X_0 - X_a)W(h_a) + \frac{(Y_0 - Y_b)}{\alpha}W(h_b) + \beta A_X S_B + (1-\beta)A_X L_B$$

(A2.2) $$Y^e = \delta_0 - (Y_0 - Y_b)W(h_b) + \frac{(X_0 - X_a)}{\alpha}W(h_a) + \beta A_Y S_A + (1-\beta)A_Y L_A,$$

where $\gamma_0 = X_0 - \alpha - Y_0/\alpha + 1/\alpha^2$ and $\delta_0 = Y_0 - \frac{1}{\alpha} - X_0/\alpha$, respectively.

To derive a reduced form, we take logs for equation (A2.1):

(A2.3) $$lnX^e = ln\left(\gamma_0 - (X_0 - X_a)W(h_a) + \frac{(Y_0 - Y_b)}{\alpha}W(h_b) + \beta A_X S_B + (1-\beta)A_X L_B\right).$$

Taking the first-order Taylor expansion yields

(A2.4) $$lnX^* + \frac{1}{X^*}(X^e - X^*) = \ln(\Phi) - \frac{(X_0 - X_a)W'(h_a^*)}{\Phi}(h_a - h_a^*) + \frac{(Y_0 - Y_b)}{\alpha}\frac{W'(h_b^*)}{\Phi}(h_b - h_b^*)$$
$$+ \frac{\beta A_X^*}{\Phi}(S_B - S_B^*) + \frac{\beta S_B^*}{\Phi}(A_X - A_X^*) + \frac{(1-\beta)A_X^*}{\Phi}(L_B - L_B^*) + \frac{(1-\beta)L_B^*}{\Phi}(A_X - A_X^*).$$

where $\Phi = \gamma_0 - (X_0 - X_a)W(h_a^*) + \frac{(Y_0 - Y_b)}{\alpha}W(h_b^*) + \beta A_X^* S_B^* + (1-\beta)A_X^* L_B^*$.

Noting that $lnX^* = \ln(\Phi)$, we can simplify equation (A2.4):

(A2.5) $$\frac{1}{X^*}(X^e - X^*) = -\frac{(X_0 - X_a)W'(h_a^*)}{X^*}(h_a - h_a^*) + \frac{(Y_0 - Y_b)}{\alpha}\frac{W'(h_b^*)}{X^*}(h_b - h_b^*)$$
$$+ \frac{\beta A_X^*}{X^*}(S_B - S_B^*) + \frac{\beta S_B^*}{X^*}(A_X - A_X^*) + \frac{(1-\beta)A_X^*}{X^*}(L_B - L_B^*) + \frac{(1-\beta)L_B^*}{X^*}(A_X - A_X^*).$$

Now we multiply and divide the term on the right side by each variable at the steady state:

(A2.6) $$\frac{1}{X^*}(X^e - X^*) = -\frac{(X_0 - X_a)W'(h_a^*)h_a^*}{X^*}\frac{(h_a - h_a^*)}{h_a^*} + \frac{(Y_0 - Y_b)}{\alpha}\frac{W'(h_b^*)h_b^*}{X^*}\frac{(h_b - h_b^*)}{h_b^*}$$

$$+\frac{\beta A_X^* S_B^*}{X^*}\frac{(S_B - S_B^*)}{S_B^*} + \frac{\beta S_B^* A_X^*}{X^*}\frac{(A_X - A_X^*)}{A_X^*} + \frac{(1-\beta)A_X^* L_B^*}{X^*}\frac{(L_B - L_B^*)}{L_B^*} + \frac{(1-\beta)L_B^* A_X^*}{X^*}\frac{(A_X - A_X^*)}{A_X^*}.$$

Using the tilde notation (i.e., $\tilde{z} = \frac{Z - Z^*}{Z^*}$) we obtain

(A2.7) $$\tilde{X} = -\frac{(X_0 - X_a)W'(h_a^*)}{X^*}\tilde{h}_a + \frac{(Y_0 - Y_b)W'(h_a^*)}{\alpha X^*}\tilde{h}_b + \beta\frac{A_X^* S_B^*}{X^*}\tilde{S}_B + (1-\beta)\frac{A_X^* L_B^*}{X^*}\tilde{L}_B$$

$$+(\beta S_B^* + (1-\beta)L_B^*)\frac{A_X^*}{X^*}\tilde{A}_X.$$

We take the same steps to obtain $\tilde{Y}$ and obtain

(A2.8) $$\tilde{Y} = -\frac{(Y_0 - Y_b)W'(h_b^*)}{Y^*}\tilde{h}_b + \frac{(X_0 - X_a)W'(h_a^*)}{\alpha Y^*}\tilde{h}_a + \beta\frac{A_Y^* S_A^*}{Y^*}\tilde{S}_A$$

$$+(1-\beta)\frac{A_Y^* L_A^*}{Y^*}\tilde{L}_A + (\beta S_A^* + (1-\beta)L_A^*)\frac{A_Y^*}{Y^*}\tilde{A}_Y.$$

Based on equations (A2.7) and (A2.8), we build a reduced form linking the equilibrium quantity of the final goods to the degree of religious homogeneity:

(A2.9) $$M_{j,n,t} = \boldsymbol{h'}_{\boldsymbol{i,n,t}}\boldsymbol{\pi_h} + \pi_S S_{n,t} + \pi_L L_{n,t} + \pi_A A_{n,t} + \vartheta_n + \delta_t + \varepsilon_{nt},$$

where $M_{j,n,t}$ indicates the equilibrium level of good $j$ for $j = \{socially\ accepted\ good,$ $discouraged\ good\}$ in country $n$ for year $t$; $\boldsymbol{h'}_{\boldsymbol{i,n,t}}$ is a vector of measures of religious homogeneity for all religions in category $i$ in country $n$ for year $t$; $S_{n,t}$ and $L_{n,t}$ measure the endowed land and endowed labor in country $n$ for year $t$, respectively; $A_{n,t}$ is a measure of the factor productivity in country $n$ for year $t$; $\vartheta_n$ is a country-specific effect, $\delta_t$ is a year-specific effect; $\varepsilon_{nt}$ is a random disturbance term; $\pi_S$, $\pi_L$, and $\pi_A$ are scalar coefficients, and $\boldsymbol{\pi_h}$ is a vector coefficient.

Table 1A. Determinants of Meat Consumption, 2002-2013, Random Effects Model

| | Beef | | Pork | | Chicken | | Mutton/lamb | | Fish | |
|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
| Christianity | -0.208 | -0.196 | -0.781*** | -0.733*** | -0.215 | -0.166 | -0.037 | -0.043 | 0.067* | 0.056 |
| | (0.207) | (0.208) | (0.203) | (0.204) | (0.159) | (0.163) | (0.071) | (0.071) | (0.040) | (0.040) |
| Christianity*Index | 0.601* | 0.582* | 1.022*** | 0.927*** | 0.397 | 0.298 | 0.338*** | 0.356*** | -0.052 | -0.025 |
| | (0.324) | (0.326) | (0.320) | (0.324) | (0.284) | (0.290) | (0.123) | (0.123) | (0.071) | (0.072) |
| Islam | -0.372* | -0.363* | -1.052*** | -1.005*** | -0.184 | -0.127 | 0.017 | 0.006 | 0.068* | 0.057 |
| | (0.203) | (0.204) | (0.204) | (0.204) | (0.155) | (0.159) | (0.070) | (0.070) | (0.039) | (0.039) |
| Islam*Index | 0.501 | 0.500 | 1.021*** | 0.890** | 0.587** | 0.489* | 0.193 | 0.225* | -0.042 | -0.026 |
| | (0.341) | (0.343) | (0.343) | (0.349) | (0.287) | (0.292) | (0.125) | (0.126) | (0.072) | (0.072) |
| Buddhism | -0.403 | -0.405 | -0.868*** | -0.894*** | -0.145 | -0.134 | -0.082 | -0.074 | 0.060 | 0.059 |
| | (0.255) | (0.255) | (0.292) | (0.290) | (0.175) | (0.178) | (0.088) | (0.088) | (0.044) | (0.044) |
| Buddhism*Index | 0.381 | 0.407 | 0.966 | 0.996* | 0.348 | 0.248 | 0.517*** | 0.527*** | 0.112 | 0.134 |
| | (0.558) | (0.559) | (0.590) | (0.587) | (0.380) | (0.388) | (0.191) | (0.192) | (0.093) | (0.093) |
| Hinduism | 0.0518 | 0.100 | -1.551** | -1.255* | -0.707* | -0.488 | 0.597*** | 0.544*** | -0.040 | -0.070 |
| | (0.581) | (0.593) | (0.666) | (0.678) | (0.417) | (0.429) | (0.178) | (0.181) | (0.100) | (0.099) |
| Hinduism*Index | -0.942 | -1.083 | 2.914* | 2.033 | 2.138** | 1.478 | -1.594*** | -1.419*** | 0.287 | 0.386 |
| | (1.367) | (1.4141) | (1.635) | (1.684) | (1.008) | (1.038) | (0.444) | (0.453) | (0.254) | (0.254) |
| Agricultural area | 0.719*** | 0.716*** | 0.613 | 0.657* | -0.396* | -0.284 | 0.404*** | 0.375*** | -0.070* | -0.089** |
| | (0.209) | (0.210) | (0.373) | (0.374) | (0.222) | (0.231) | (0.084) | (0.084) | (0.036) | (0.037) |
| Employment | 0.249*** | 0.247*** | 0.191*** | 0.174*** | 0.216*** | 0.218*** | 0.025 | 0.028 | -0.013 | -0.014 |
| | (0.0491) | (0.050) | (0.049) | (0.050) | (0.051) | (0.051) | (0.021) | (0.021) | (0.013) | (0.013) |
| Agrisector growth | -0.001 | -0.002 | -0.002 | -0.003 | 0.008 | 0.006 | -0.010*** | -0.010*** | -0.003 | -0.002 |
| | (0.006) | (0.006) | (0.006) | (0.006) | (0.008) | (0.008) | (0.003) | (0.003) | (0.002) | (0.002) |
| Index | -55.755* | -55.480* | -131.78*** | -123.58*** | -43.510 | -35.911 | -21.720* | -23.283** | 8.700 | 7.085 |
| | (31.974) | (32.053) | (31.195) | (31.409) | (26.537) | (26.965) | (11.627) | (11.633) | (6.675) | (6.665) |
| Urbanization | 0.193*** | 0.179*** | 0.184*** | 0.0979 | 0.515*** | 0.423*** | 0.054*** | 0.084*** | 0.020** | 0.040*** |
| | (0.056) | (0.067) | (0.063) | (0.076) | (0.038) | (0.048) | (0.019) | (0.023) | (0.009) | (0.011) |
| FDI | -0.005 | 0.076*** | -0.033* | 0.006 | -0.013 | -0.066** | -0.002 | 0.017 | 0.004 | -0.005 |
| | (0.015) | (0.024) | (0.017) | (0.026) | (0.021) | (0.030) | (0.007) | (0.011) | (0.005) | (0.007) |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| GDP growth | 0.077*** | -0.006 | 0.002 | -0.035** | -0.074** | -0.016 | 0.019* | -0.002 | -0.004 | 0.004 |
| | (0.024) | (0.015) | (0.026) | (0.017) | (0.031) | (0.021) | (0.011) | (0.007) | (0.007) | (0.005) |
| Stability | 0.235 | 0.221 | 0.314 | 0.329 | 1.030** | 0.983** | 0.514*** | 0.495*** | 0.143 | 0.184* |
| | (0.371) | (0.371) | (0.397) | (0.398) | (0.429) | (0.429) | (0.159) | (0.159) | (0.098) | (0.099) |
| Female employ | | 0.111 | | -0.026 | | -0.077 | | 0.057* | | -0.007 |
| | | (0.094) | | (0.079) | | (0.094) | | (0.032) | | (0.025) |
| Age0-14 | | -0.035 | | -0.207** | | -0.266*** | | 0.072** | | 0.058*** |
| | | (0.087) | | (0.105) | | (0.075) | | (0.033) | | (0.018) |
| N | 1099 | 1099 | 891 | 891 | 1068 | 1068 | 960 | 960 | 1260 | 1260 |
| adj. $R^2$ | 0.178 | 0.175 | 0.098 | 0.121 | 0.528 | 0.483 | 0.152 | 0.154 | 0.290 | 0.306 |

Notes: Standard errors in parentheses. * p<0.1 ** p<0.05 *** p<0.01

Table 2A. Data Definitions and Sources

| Variable | Unit | Definition | Source |
|---|---|---|---|
| <u>Estimation</u> | | | |
| Beef | kg per capita | production - export + import | Food and Agriculture Organization of the United Nations STAT (FAOSTAT) |
| Pork | kg per capita | production - export + import | |
| Chicken | kg per capita | production - export + import | |
| Mutton/lamb | kg per capita | production - export + import | |
| Fish | kg per capita | production - export + import | |
| Christianity | % | proportion of Christian population | Association of Religion Data Archives, American Religious Identification Survey, Integrated Public Use Microdata Series International, Religions of the World, A Comprehensive Encyclopedia of Beliefs and Practices, World Religion Database |
| Islam | % | proportion of Muslim population | |
| Buddhism | % | proportion of Buddhist population | |
| Hinduism | % | proportion of Hindu population | |
| Non-affiliated | % | proportion of non-religiously affiliated population | |
| Agricultural area | per capita | agricultural area (1000ha) | FAOSTAT |
| Employment | % of total | employment to population ratio, 15+ | World Bank Indicator (WBI) |
| Agrisector growth | % | Agriculture, Forestry and Fishing, growth rate | FAOSTAT |
| Urbanization | % of total | urban population | WBI |
| FDI | % of GDP | foreign direct investment, net inflow | WBI |
| GDP growth | % | GDP growth | WBI |
| Stability | -2.5 (lowest stability) 2.5 (highest stability) | political stability and absence of violence/terrorism | WBI |
| Female employ | % | % of female employment | WBI |
| Age 0-14 | % | Population ages 0–14 | WBI |
| <u>Elasticity</u> | | | |
| Emissions | | | |
| Beef | kg $CO_2$-eq per capita | meat, beef emissions | FAOSTAT |
| Pork | kg $CO_2$-eq per capita | meat, pork emissions | FAOSTAT |
| Chicken | kg $CO_2$-eq per capita | meat, chicken emissions | FAOSTAT |
| Mutton/lamb | kg $CO_2$-eq per capita | meat, mutton/lamb emissions | FAOSTAT |
| Emission Intensity | | | |
| Beef | kg $CO_2$-eq per kg carcass weight (CW) | meat, beef emissions intensity | FAOSTAT |
| Pork | kg $CO_2$-eq per kg CW | meat, pork emissions intensity | FAOSTAT |
| Chicken | kg $CO_2$-eq per kg CW | meat, chicken emissions intensity | FAOSTAT |
| Mutton/lamb | kg $CO_2$-eq per kg CW | meat, mutton/lamb emissions intensity | FAOSTAT |

## Appendix C. List of Countries by Region

Region 1: Non-Muslim Africa (sub-Saharan countries)
Angola, Botswana, Cameroon, Central African Republic, Congo, Rep., Benin, Gabon, Ghana, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mozambique, Namibia, Nigeria, Guinea-Bissau, Rwanda, Sierra Leone, South Africa, Swaziland, Togo, Uganda, Burkina Faso, Ethiopia, Zambia, Sudan (27)

Region 2: Muslim Countries
Albania, Algeria, Bangladesh, Chad, Azerbaijan, Egypt, Arab Rep., Djibouti, Gambia, Bosnia and Herzegovina, Guinea, Indonesia, Iran, Islamic Rep., Iraq, Jordan, Kyrgyz Republic, Kuwait, Lebanon, Malaysia, Mali, Mauritania, Morocco, Niger, Pakistan, Saudi Arabia, Senegal, Tajikistan, Turkmenistan, Oman, Tunisia, Turkey, United Arab Emirates, Uzbekistan, Yemen, Rep. (33)

Region 3: (non-Muslim) South and East Asia
Australia, Sri Lanka, Hong Kong SAR, China, India, Japan, Cambodia, Korea, Rep., Lao PDR, Mongolia, Nepal, New Zealand, Philippines, Timor-Leste, Thailand, Vietnam (15)

Region 4: Latin America
Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Ecuador, El Salvador, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Uruguay, Venezuela, RB (19)

Region 5: (non-Muslim) Former-Socialist countries
Armenia, Bulgaria, Belarus, Estonia, Georgia, Hungary, Croatia, Kazakhstan, Latvia, Lithuania, Poland, Romania, Russian Federation, Slovenia, Slovak Republic, Ukraine, Montenegro (17)

Region 6: North Atlantic countries
Austria, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States, Belgium (18)

Notes: Israel is considered an isolated state and not included in the regional categories. The number of countries is in parentheses.

CHAPTER THREE

# THE EFFECT OF A GOVERNMENT PLANNER'S EDUCATIONAL BACKGROUND ON ENVIRONMENTAL OUTCOMES IN AUTOCRATIC REGIMES


## Abstract

This study addresses the role of a government planner's sensitivity to the adverse impact of pollution when deciding environmental policies in both autocratic and democratic regimes. We test if the government planner's academic discipline affects environmental quality of their nation through the choice of environmental regulations. We estimate the effect of a head of state's university major on environmental outcomes using panel data from 23 countries under autocratic and 46 under democratic regimes from 1981 to 2005. In autocratic countries, our empirical findings suggest that heads of state educated in business or economics lead to a higher increase in sulfur dioxide ($SO_2$) emissions (0.020–0.045 metric tons per capita) relative to heads of state educated in another discipline, while the relative negative effect of discipline disappears in the sample of democratic countries.

## 1. Introduction

Rising individual education levels and economic development provide an underlying mechanism for explaining the environmental Kuznets curve, a hypothesized relationship between environmental quality and per capita income (Panayotou, 1997; Stern, 2004). The educated are more aware of environmental issues and are likely to have stronger preferences for environmental amenities (Farzin and Bond, 2006). They organize advocacy groups to express their demands for environmental policies through existing political channels (Fredriksson et al., 2005). Along with voting, these activities influence policy makers to implement more stringent policies. Since access to such political participation is restricted in autocratic regimes, existing studies that link the role of education to environmental consequences mostly focus on the impact of citizens' environmental attitudes in democratic countries (Bimonte, 2002).

However, understanding the underlying mechanism that determines the stringency of environmental regulations in autocratic countries is of great importance because considerable environmental degradation has taken place in regions dominated by autocratic regimes. The World Health Organization (WHO, 2016) estimates that there are clusters of significant air pollution exposure in Africa, the Middle East, and China. Half of the ten worst performers on environmental issues in the world are autocratic regimes (Hsu et al., 2016).[12] China and Russia—both autocratic countries—are the largest contributors to greenhouse gas emissions (Boden et al., 2017).

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[12]The ten worst performers are Somalia, Eritrea*, Madagascar*, Niger, Afghanistan, Chad*, Mali, Bangladesh, Mozambique*, and the Democratic Republic of Congo*. Autocratic countries are marked with an asterisk (*).

Following Geddes et al., (2014), we define as autocratic any regime in which i) an executive achieves power through undemocratic means and establishes new rules for choosing leaders and policies within one's inner circle, ii) a government changes rules to limit competition in elections after achieving power through competitive elections, or iii) the military prevents one or more parties from competing or dictates policy choice in critical policy areas despite the existence of competitive elections.

To understand the process of environmental policy formation in autocratic regimes, it is key to develop a novel approach centered on the subject who actually makes the final decision on the environmental policies. In the absence of the publicly accessible political channels, one of the critical determinants in the policy-making process could be the government planner's attitude toward environmental issues. This agrees with Farzin and Bond's (2006) view that the supply of environmental policies depends on politicians' sensitivity to pollution's adverse social impacts. For example, a good case would be that of the Sultanate of Oman. The leader of the country, His Majesty Sultan Qaboos bin Said, is regarded as the Head of State and the Supreme Commander where his person is inviolable, and the respect of him is a duty and his command is obeyed. [13] Through royal decree such as the "Law of Conservation and Environment & Prevention (Royal Decree No. 114/2001)", "Handling chemicals (Royal Decree No. 46/95)", "Law on Protection of Sources of Portable Water from Pollution (Royal Decree No. 115/2001)" to name just a few are all ideas that were either initiated internally via the Ministry of Environment and Climate

[13] Article 41 from the basic law of Oman:

http://www.wipo.int/edocs/lexdocs/laws/en/om/om019en.pdf

Affairs[14], or pushed forward by the Environment Society of Oman[15] or international treaties on the environment. As all these agreements were issues as royal decrees signed and approved by the Sultan himself instead of only being issued as Ministerial decisions. This is a clearly indication that His Majesty the Sultan is spearheading and directly involved in policy formation to guard Oman's environment. We thus expect that education plays a role in determining the supply of environmental policies through shaping the government planner's attitudes toward environmental issues in autocratic regimes.

This study investigates how the educational background of a government planner impacts environmental outcomes in autocratic regimes. First, we develop a partial equilibrium model to show that less-stringent regulation would be implemented in autocratic regimes if the government planner had been educated in an academic discipline not conducive to be conscious of environmental damages. However, the negative effect of the planner's educational discipline disappears in democratic regimes. We then test the theoretical link in our model by estimating the effect of a university major of heads of state on sulfur dioxide ($SO_2$) emissions, a production-based pollution emission indicator.

The level of education and the field of education are both considered when analyzing the role of educational background in which an individual is developing his/her environmental attitudes. Studies focusing on the influence of the education level suggest that individuals with higher levels of education—compared to individuals with lower levels—express greater concern about the environment and are more likely to engage in environmentally responsible behaviors

[14] https://meca.gov.om/en/index.php

[15] http://www.eso.org.om/index.php

(Hines et al., 1986,1987; Ostman and Parker, 1987; Scott and Willits, 1994). Xiao and McCright (2007) suggest that education and political orientation are among the most robust predictors of environmental concern and behavior. Using survey data, many studies show evidence that the level of education (individuals with a bachelor's degree and above) is positively correlated with increased awareness of environmental topics and responsible attitudes towards the environment (Blake, 2001; Buttel and Flinn, 1978; Dietz et al., 1998; Mobly et al. 2010).

Studies that examine the influence of the field of education provide empirical evidence that university students' attitudes toward environmental issues vary significantly depending on their academic major. Tikka et al. (2000) show that university students in biology have more positive attitudes and knowledge about environmental issues relative to those in other subjects, while economics students have more negative attitudes. Benton (1994) and Synodinos (1990) compare business and non-business students with respect to their degree of environmental concern and find that business students are less concerned and less willing to engage in environmentally responsible behaviors.

In our model, we assume that a government planner educated in an academic discipline that would increase their awareness of environmental damages will implement more stringent regulations, placing a greater weight on disutility from environmental damages to the detriment of consumer welfare. Such weight is the measure of the planner's environmental awareness. In democratic regimes, with a high political participation of citizens, regulatory stringency becomes subject to the influence of lobby groups together with the planner's weight.

To test the theoretical results, we collect a unique dataset from the Barcelona Center for International Affairs on the university majors of heads of state paired with country-level panel data on $SO_2$ emissions from Smith et al. (2011). The dataset includes observations on 23 autocratic countries from 1981 to 2005 and 45 democratic countries from 1994 to 2005. The university majors of heads of state—a proxy of educational background—are divided into five categories: STEM and health, business and economics, law and social sciences, humanities, and military academy. We hypothesize that business and economics majors will be less aware of environmental issues than planners who majored in other disciplines; business and economics is the measure of the academic disciplines that influence the government planner to be less aware of environmental issues relative to the rest of the disciplines.

We are aware that a planner's environmental attitudes could have been shaped earlier in life, affecting their choice of academic field at the university level. In recognition of the potential endogeneity of the planner's academic major, an instrument—adolescent fertility rate in the year when he/she was eighteen years old—is identified for the planner's academic major. The adolescent fertility rate affects educational investment by individuals during their age of adolescence, when academic interests are developed and planning for the future begins (WHO, 2017); which, in turn, affects the academic discipline choice. We separately estimate the effect of a head of state's academic background on the pollution indicator for two types of regimes—autocracy and democracy—using time fixed effects, ordinary least squares (OLS), and instrumental variables (IV) models.

We find that the relative effects of business and economics on $SO_2$ emissions are positive and significant compared to the other fields in all specifications in the autocratic country sample. Heads of state educated in business and economics demonstrate an increase in $SO_2$ emissions of 0.020–0.045 metric tons per capita relative to heads of state educated in another discipline. We find that in the first stage, the adolescent fertility rate of the year when heads of state were eighteen has a negative and significant effect on business and economics, and it is not a weak instrument according to our Stock-Yogo test results. The coefficients of business and economics after instrumenting are close in magnitude to those generated from the time fixed effects and OLS models. Our estimation results appear to be fairly consistent across specifications and models. In addition, we find no evidence that planners' academic fields affect $SO_2$ emissions in the democratic country sample.

The remainder of the article is organized as follows: Section 2 describes the theoretical model. Based on the theoretical model, we outline the empirical model in Section 3 and describe the data in Section 4. We interpret the results from the estimation and calculate the elasticity based on the results in Section 5. Finally, Section 6 concludes.

## 2. Theoretical Framework

### *2.1 Assumptions*

We build models for autocratic and democratic regimes based on the framework suggested by Fredriksson and Svensson (2003) and Fredriksson et al. (2005). Consider a small, open economy with consumers and two types of industries—one clean and the other dirty—. The population of this economy is normalized to 1. The clean industry produces a numeraire good, $z$, under constant returns to scale. The dirty industry produces a non-numeraire good, $x$. Assuming that each industry sells its output in a competitive market, the prices of good $z$ and good $x$ are 1 and $p^*$, respectively. There are $n$ identical firms in the dirty industry, each of which produces $x_i$. The aggregate output of $x$ is defined as $X$, where $nx_i \equiv X$. The dirty industry generates pollution that causes disutility to consumers. The per unit pollution damage, $\theta$, depends on the amount, $h$, that a firm invests on pollution control per unit of output. The aggregate pollution from the dirty industry is thus given by

(1) $$E^A = \theta(h)X.$$

The per unit pollution damage decreases in pollution control investment at an increasing rate, (i.e., $\theta_h < 0$ and $\theta_{hh} > 0$).

The government regulates the negative externality by implementing a pollution tax, $\tau$, on per unit pollution damage. Given the pollution tax, firm $i$ in the dirty sector maximizes its profit:

(2) $$\pi_i(\tau, p^*) = \max_{x_i, h_i}\{p^* x_i - \mathrm{V}(x_i, h_i) - \tau\theta(h_i)x_i\},$$

where $\mathrm{V}(x_i, h_i)$ is a convex cost function when producing $x_i$ and investment of $h_i$ for pollution control per unit of output (i.e., $V_x > 0, V_{xx} > 0, V_h > 0, V_{hh} > 0$ and $V_{xh} > 0$). The first-order conditions yield equilibrium values of $x_i$ and $h_i$, defined as a function of $\tau$ and $p^*$: $x_i(\tau, p^*)$ and $h_i(\tau, p^*)$. Not surprisingly, the pollution tax lowers output but increases investment in pollution control (see Appendix A). Thus, the pollution tax revenues collected from $n$ identical firms in the dirty industry can be expressed as

(3) $$T = \tau\theta(h)nx_i(\tau, p^*) \equiv \tau\theta(h)X(n, \tau, p^*).$$

Tax revenues are assumed to be equally distributed to all consumers.

A consumer decides how much to consume of each good (e.g., *x* or *z*) given their budget constraint: $I = c^z + p^* c^x$, where $I$ is income and $c^z$ and $c^x$ are consumption levels of numeraire clean good $z$ and non-numeraire dirty good $x$, respectively. A quasi-linear utility function (linear in consumption of $z$, concave in consumption of $x$, and additively separable across goods) is assumed:

(4) $$U = c^z + u(c^x) - X\theta.$$

We derive two consumption functions, solving an unconstrained maximization problem: $c^x = u_{c^x}^{-1}(p^*) = d(p^*)$ and $c^z = I - p^* d(p^*)$. An individual's indirect utility function is then

(5) $$\mathrm{V}(p^*, \tau, I) = \delta(I, p^*) - X\theta,$$

where $\delta(I, p^*) \equiv I - p^* d(p^*) + u[d(p^*)]$. Note that $\delta(I, p^*)$ represents consumer surplus from consumption of dirty good $c^x$.

The government planner attempts to find an optimal tax rate to maximize aggregate welfare, which is the sum of aggregate profits, consumer surplus net of disutility from the negative externality, and pollution tax revenues (Fredriksson and Svensson, 2003; Fredriksson et al., 2005). If the planner is benevolent, the following welfare function is counted:

(6) $$\Omega^A(n, \tau, p^*, I) = n\pi_i(\tau, p^*) + \delta(I, p^*) + \tau\theta\big(h(\tau, p^*)\big)X(\tau, p^*) - \theta\big(h(\tau, p^*)\big)X(\tau, p^*).$$

Solving equation (6) for $\tau$ derives the expected result that the Pigouvian tax is equivalent to the marginal disutility of pollution 1.

*2.2 Autocracy*

We suggest a social welfare function that captures the extent of a government planner's awareness about environmental damages in autocratic regimes. A planner weighs disutility from environmental damages based on their environmental awareness, which can be shaped by a variety of individual experiences and social circumstances. Studies analyzing an individual's attitudes toward environmental issues have suggested that academic background is a critical factor in shaping an individual's environmental awareness on which the influence of academic disciplines significantly varies (Benton, 1994; Tikka et al., 2000; Synodinos, 1990). Taking their view, we assume that the weight that the planner places on the disutility is dependent on academic background. The modified social welfare function is

$$\Omega^{AS}\left(n,\tau,p^*,I,s^j\right) = n\pi_i(\tau,p^*) + \delta(I,p^*) + \tau\theta\left(h(\tau,p^*)\right)X(\tau,p^*) - w(s^j)\theta\left(h(\tau,p^*)\right)X(\tau,p^*), \tag{7}$$

where $w\left(s^j\right)$ is the relative weight the government planner places on disutility from pollution; a larger weight implies that the planner is more concerned with the consequences of environmental damages. Additionally, $s^j\ \forall\ j\ \in g,b$ is the planner's educational background and $s^g$ denotes academic disciplines that influence an individual to be more aware of environmental issues relative to academic disciplines $s^b$. Thus, a planner educated in academic disciplines $s^b$ has less interest in environmental issues than one educated in $s^g$. The value of the relative weight exists in the following range: $w(s^b)\ \in [0,1)$ and $w(s^g)\ \in [1,\infty)$.

The first-order condition of equation (7) characterizes the new equilibrium pollution tax rate denoted as $\tau^*$:

$$[\tau^* - w\left(s^j\right)][X_\tau(\tau,p^*)\theta\left(h(\tau^*,p^*)\right) + X(\tau,p^*)\theta_h\left(h(\tau,p^*)\right)h_\tau(\tau,p^*)]\ = 0 \tag{8}$$

We find that the condition requires the equilibrium tax rate to be equivalent to the relative weight (i.e., $\tau^* = w\left(s^j\right)$). In addition to the marginal consumer disutility of pollution, this weight plays a key role in determining the pollution tax, implying that if a government planner were educated in an academic discipline that shapes one to be less conscious of environmental damages, a less-stringent regulation would be implemented.

*2.3 Democracy*

In democratic regimes, $n$ firms and individuals can independently organize a lobby group to obtain a desirable environmental regulation. The proportion of a population participating in an environmental lobby group is $m^g$. The interaction between the government and the lobby groups follows a two-stage game. In the first stage, a lobby group comprising firms in the dirty sector and an environmental group comprising consumers present contribution-expenditure schedules to the government, promising to provide contributions to the government planner if a particular pollution tax rate, $\tau$, is chosen. Each lobby group takes the contribution schedule of the other lobby group as given. In the second stage, the government planner determines the pollution tax rate, taking into account overall social welfare and the political contributions from the lobby groups.

The environmental lobby group is funded by voluntary participant donations, where $\alpha$ is the portion of a participant's income dedicated to lobbying. The indirect utility of a participant is then $V^g(p^*, \tau, \alpha, I) = \delta^g(p^*, \alpha, I) - X\theta$, where $\delta^g(p^*, \alpha, I) \equiv (1-\alpha)I - p^* d(p^*) + u[d(p^*)]$. The expenditure-contribution schedule the environmental lobby group offers, $\Lambda^g$, is a continuous function of the pollution tax rate. The volume of political contributions is dependent on $\alpha$ and the number of participants, $m^g$. An increase in the number of consumers joining the lobby group and in the portion of their donated income increases the volume of contributions. The welfare of the environmental lobby group is

(9) $$W^g = m^g V^g(p^*, \tau, \alpha, I) - \Lambda^g(\tau, m^g, \alpha).$$

The welfare of the business lobby group in the dirty sector is the sum of the aggregate profits, net of political contributions:

(10) $$n\pi^i(\tau, p^*) - \Lambda^f(\tau),$$

where $\Lambda^f(\tau)$ is the contribution schedule offered by the business lobby group. The lobbying schedule also consists of a continuous function of the pollution tax rate.

### *2.3.1 Government Decision*

The aggregate welfare in this democratic economy is a sum of aggregate profits, individual welfare net of disutility from negative externalities, and tax revenues:

(11) $$W^s \equiv \Omega^{ws}(\tau, p^*, I, \alpha, s^j) = n\pi_i(\tau, p^*) + m^g\delta^g(p^*, \alpha, I) + (1 - m^g)\delta(I, p^*)$$
$$-w(s^j)\theta(h(\tau, p^*))X(\tau, p^*) + \tau\theta(h(\tau, p^*))X(\tau, p^*).$$

The second and third terms are measures of welfare of lobbying participants and non-participants, respectively; the fourth term is the government planner's weighted disutility.

Following Grossman and Helpman (1994), a government planner who cares about lobby contributions as well as aggregate welfare maximizes the following function:

(12) $$\max_{\tau} G \equiv \Omega^G(\tau, p^*, I, \alpha) = W^s + \Lambda^g(\tau, m^g, \alpha) + \Lambda^f(\tau).$$

The aggregate lobbying contributions in the government's welfare function can be viewed as monetary values that can be used for next election or used privately by the government planner. The first-order condition of the government's problem is

(13) $$\frac{\partial G}{\partial \tau} = \left(\tau - w(s^j)\right)\left(X_\tau\theta(h(\tau, p^*)) + X(\tau, p^*)\theta_h h_\tau\right) + \Lambda_\tau^g + \Lambda_\tau^f = 0.$$

The government equates the marginal benefits from implementing the pollution tax and marginal benefits from gaining lobby contributions from the environmental lobby group to the marginal cost of losing lobby contributions from the business lobby group.

We use the common-agency model to reach the equilibrium that maximizes the joint surplus of the government and lobby groups (e.g., Fredriksson and Svensson 2003; Fredriksson et al., 2005):

(14) $$\max_{\tau} \Omega^{ws}(\tau, p^*, I, \alpha, s^j) + n\pi_i(\tau, p^*) + m^g[\delta^g(p^*, \alpha, I) - \theta(h(\tau, p^*))X(\tau, p^*)].$$

The first -order condition with respect to $\tau$ yields

$$(15) -\theta\big(h(\tau^*, p^*)\big)X(\tau^*, p^*) + (\tau^* - w(s^j) - m^g)\big(\underbrace{(X_\tau\theta\big(h(\tau^*, p^*)\big) + X(\tau^*, p^*)\theta_h h_\tau)}_{(a)} = 0.$$

The term $(\tau^* - w(s^j) - m^g)$ should be negative to meet the equilibrium condition, as the two other terms are negative where the term $(a)$ is negative because $X_\tau < 0$, $\theta_h < 0$, and $h_\tau > 0$. That is, the equilibrium tax rate $\tau^*$ should meet the following condition: $\tau^* < w(s^j) + m^g$, which implies that the equilibrium tax in a democracy is indeterminate in size, unlike the case of autocracy, where the tax rate is required to be equivalent to the relative weight a government planner places on disutility. However, there exists a maximum rate to impose, which depends on the planner's weight and the proportion of a population participating in the environmental lobby group. An increase in the prevalence of environmentalists in a democratic regime acts to increase the maximum tax rate.

Finally, the pollution tax determines the level of aggregate pollution of the economy through its impact on the amount of investment in pollution control and the production of the dirty good, according to equation (1):

$$(16) \qquad E^r = \theta\big(h(\tau^*, p^*)\big)\, X(\tau^*, p^*),$$

where $E^r$ is the level of aggregate pollution for $r = \{A, D\}$, where $A$ denotes an autocratic regime and $D$ denotes a democratic regime.

## 3. Empirical Model

We separately estimate the effect of a government planner's educational background on environmental outcomes for two different types of regimes—autocracy and democracy—following our theoretical results. For autocratic regimes, we develop a reduced form using a simplified expression of the equilibrium tax for empirical work from equation (8): $\tau^* =$

$\zeta(s^j, n, I, p^*)$. The reduced model can be specified by combining the expression with equation (16): $E^A = \xi(\tau^*, p^*) = \xi\left(s^j, n, I, p^*\right)$. The empirical model is then expressed as

$$(17) \qquad E^A{}_{it} = \pi^A{}_s s^A{}_{it} + \pi^A{}_n n^A{}_{it} + \pi^A{}_y I^A{}_{it} + \pi^A{}_p p^A{}_{it} + \varepsilon_t + \mu_{it},$$

where $s^A{}_{it}$ is a measure of the government planner's educational background in autocratic country $i$ at year $t$, $n^A{}_{it}$ is a measure of the number of firms in autocratic country $i$ at year $t$, $I^A{}_{it}$ is a measure of the consumer income level in autocratic country $i$ at year $t$, $p^A{}_{it}$ is a measure of the price of the dirty good in autocratic country $i$ at year $t$, $\varepsilon_t$ is a year fixed effect, and $\mu_{it}$ is a random disturbance term.

Likewise, applying a simplified expression of the equilibrium tax for democratic regimes from equation (15), $\tau^* = \zeta(s^j, n, I, p^*, m^g)$, we specify the reduced model again, combining it with equation (16):

$$(18) \qquad E^D{}_{it} = \pi^D{}_s s^D{}_{it} + \pi^D{}_n n^D{}_{it} + \pi^D{}_y I^D{}_{it} + \pi^D{}_p p^D{}_{it} + \pi^D{}_m m^D{}_{it} + \varepsilon_t + \mu_{it},$$

where $m^D{}_{it}$ is a measure of the proportion of the population participating in the environmental lobby groups in democratic country $i$ at year $t$ and the remaining variables are as described in equation (17).

For the government planner's educational background to affect aggregate pollution in autocratic regimes, we expect $\pi^A{}_s$ to be statistically significant. The sign of $\pi^A{}_s$ is expected to be positive for academic disciplines influencing less awareness of environmental issues but to be negative otherwise. However, it is unlikely that the government planner's own attitude directly affects the policy outcome in democratic regimes, because the planner is not free from lobbying and the electoral system (Fredricksson and Wollscheid, 2006). We thus expect $\pi^D{}_s$ to be statistically insignificant for democratic regimes.

We encounter three important issues regarding the estimation of equations (17) and (18). First, our main explanatory variable, the government planner's educational background, barely varies over time, so it is inappropriate to use the unit fixed effects model to estimate the variable coefficient. The models we alternatively choose to employ are OLS and a time fixed effects model with year dummies, introducing control variables that measure geographic and inherited characteristics of states such as forest area, temperature, number of neighboring countries, and religious prevalence to prevent potential omitted variable bias. OLS has been widely applied in studies analyzing institutional effects and political determinants without much variation. (Acemoglu et al., 2002; Beramendi and Cusack, 2009; Wallerstein and Moene, 2003). Acemoglu et al. (2002) explain that a full set of country dummies are not included in their study because their interest is in the historically determined component of institutions.

Another issue is the potential endogeneity of our main variable to be measured with the government planner's university major. The planner's environmental awareness could have been developed earlier than their university education, affecting their choice of academic field. An estimation that does not account for this endogeneity problem is likely to bias the coefficient estimate of the variable. To cope with the issue, we additionally estimate equations (17) and (18) using an IV model. We choose as an instrumental variable, adolescent fertility rate in the year when the planner was eighteen years old, which reflects educational condition during their age of adolescence, when academic interests are developed and planning for the future begins (WHO, 2017). Higher adolescent fertility rates might indicate that the young are less likely to attend secondary education, instead joining the workforce to finance their family. Filmer and Pritchett (1999) who examine the effect of household wealth on educational attainment find that in many countries the bulk of the deficit from education comes from the poor. These findings indicate that high fertility rate that leads to a reduction in household income hampers the pursuit of education, that is, school enrollment. Another possible scenario is that—even given an opportunity to attend secondary education—they may prefer to attend a military academy that is tuition-free and guarantees the future job.

Lastly, we introduce control variables that capture state-level characteristics such as measurements of institutional quality, openness to trade, and socioeconomic characteristics, which are potential determinants of environmental condition (Fredriksson et al., 2005; Galinato and Galinato, 2012). Finally, we cluster observations to account for autocorrelation among planners within countries.

## 4. Data

In our analysis, we seek to explain aggregate pollution emissions including a series of variables including the government planner's educational background. To measure the effects of the government planner's educational background, we collect a unique dataset on the university majors of heads of state from the Barcelona Center for International Affairs that compiles biographies of heads of state in the world. We then match these with country-level panel data on $SO_2$ emissions from Smith et al. (2011). The dataset includes data on 23 autocratic countries from 1981 to 2005 and 45 democratic countries from 1994 to 2005. We identify autocratic countries, which include party-based regimes, military regimes, personalist regimes, and monarchical regimes (Geddes et al. 2014). Table 1 presents the summary statistics, and Table 2A presents data definitions and sources. Appendix B lists autocratic and democratic countries in the sample.

Table 1. Summary Statistics

| Variable | Autocracy Obs. | Autocracy Mean | Autocracy Std. Dev. | Autocracy Min | Autocracy Max | Democracy Obs. | Democracy Mean | Democracy Std. Dev. | Democracy Min | Democracy Max |
|---|---|---|---|---|---|---|---|---|---|---|
| $SO_2$ | 172 | 0.016 | 0.019 | 0.0004 | 0.096 | 272 | 0.020 | 0.025 | 0.001 | 0.142 |
| STEM and health | 172 | 0.366 | 0.483 | 0 | 1 | 272 | 0.055 | 0.229 | 0 | 1 |
| Business and economics | 172 | 0.099 | 0.299 | 0 | 1 | 272 | 0.268 | 0.444 | 0 | 1 |
| Law and social science | 172 | 0.244 | 0.431 | 0 | 1 | 272 | 0.585 | 0.494 | 0 | 1 |
| Humanities | 172 | 0.058 | 0.234 | 0 | 1 | 272 | 0.015 | 0.121 | 0 | 1 |
| Military academy | 172 | 0.128 | 0.335 | 0 | 1 | 272 | 0.077 | 0.267 | 0 | 1 |
| University | 172 | 0.895 | 0.307 | 0 | 1 | 272 | 1 | 0 | 1 | 1 |
| Birth year | 172 | 1939.587 | 12.379 | 1921 | 1971 | 272 | 1943.960 | 9.012 | 1916 | 1960 |
| International | 172 | 0.500 | 0.501 | 0 | 1 | 272 | 0.353 | 0.479 | 0 | 1 |
| Industry | 172 | 36.365 | 15.090 | 9.843 | 75.468 | 272 | 30.782 | 6.740 | 17.412 | 57.796 |
| GDP growth | 172 | 5.480 | 4.046 | -7.359 | 26.400 | 272 | 3.616 | 3.443 | -10.894 | 33.736 |
| Interest rate | 172 | 8.445 | 30.624 | -94.220 | 252.115 | 272 | 7.631 | 12.304 | -35.314 | 93.915 |
| FDI net inflow | 172 | 4.708 | 8.205 | -4.844 | 55.078 | 272 | 3.465 | 4.391 | -5.670 | 30.946 |
| Fragility | 172 | 13.994 | 4.949 | 2 | 23 | 272 | 5.445 | 5.783 | 0 | 20 |
| Civil liberty | 172 | 5.233 | 0.975 | 3 | 7 | 272 | 2.184 | 1.135 | 1 | 5 |
| Forest area | 172 | 28.481 | 23.721 | 0 | 66.911 | 272 | 34.020 | 18.382 | 6.594 | 73.094 |
| Temperature | 172 | 21.026 | 7.090 | -5.809 | 28.108 | 272 | 16.632 | 7.773 | 1.211 | 27.930 |
| Christianity | 172 | 0.371 | 0.339 | 0.002 | 0.955 | 272 | 0.697 | 0.295 | 0 | 0.974 |
| Islam | 172 | 0.405 | 0.387 | 0 | 0.991 | 272 | 0.060 | 0.152 | 0 | 0.886 |
| Buddhism | 172 | 0.058 | 0.129 | 0 | 0.492 | 272 | 0.060 | 0.204 | 0 | 0.945 |
| Hinduism | 172 | 0.008 | 0.019 | 0 | 0.122 | 272 | 0.029 | 0.136 | 0 | 0.808 |
| Landlocked | 172 | 0.145 | 0.353 | 0 | 1 | 272 | 0.063 | 0.243 | 0 | 1 |
| Land neighbors | 172 | 5.599 | 3.749 | 0 | 16 | 272 | 3.489 | 2.455 | 0 | 10 |
| Urbanization | 172 | 46.289 | 22.853 | 13.827 | 100 | 272 | 65.742 | 20.266 | 18.382 | 97.400 |
| Ages 0–14 | 172 | 37.250 | 9.118 | 15.174 | 50.026 | 272 | 25.560 | 8.613 | 13.804 | 43.907 |
| Adolescent fertility 18 | 62 | 115.956 | 59.585 | 18.229 | 234.684 | 175 | 68.642 | 41.984 | 4.120 | 158.739 |
| Enrollment-secondary education | 224 | 52.543 | 31.623 | 5.165 | 112.622 | 441 | 89.244 | 27.575 | 11.704 | 160.619 |
| Adolescent fertility | 224 | 78.422 | 61.327 | 6.600 | 217.097 | 441 | 41.717 | 34.222 | 1.916 | 157.604 |

As a proxy of aggregate pollution, we use an indicator of $SO_2$ emissions, which arise mainly from fossil fuel combustion at power plants and other industrial facilities (EPA, 2015). Thus, $SO_2$ is referred to as a production-based air pollution indicator (Seldon and Song, 1994; Scrieciu, 2015) and reflects the stringency of environmental regulations on the dirty industry.

The measure of the government planner's educational background is the university major of heads of state. To identify a head of state for a democratic country, we account for the government type of the state using the World Factbook. A prime minister is considered the head of state in a parliamentary system, while a president is considered the head of state in a presidential system. We divide academic disciplines into five categories: STEM and health, business and economics, law and social sciences, humanities, and military academy. The most dominant field in autocratic countries is STEM and health (36.6%), followed by law and social sciences (24.4%) and military academy (12.8%). In democratic countries, law and social sciences (58.5%) is the most dominant field, followed by business and economics (26.8%). We also include a variable—university—that indicates whether a head of state received a university education. In our autocratic country sample, 89.5% of heads of state received a university education. Since there is no planner without a university degree in our democratic country sample, the variable is not applied to these estimations.[16]

[16] The average distribution of the academic fields for students in tertiary education is quite different from the distribution of the academic fields for heads of states. According to the UNESCO Institute for Statistics (2018), the most dominant field for students in tertiary education in both autocratic and democratic countries from 1998 to 2005 is STEM and health, 29.6% and

Of them, business and economics majors are used as the measure of the academic disciplines that influence the planner to be less aware of environmental issues (denoted as $s^b$ in Section 2.2) relative to the other disciplines (denoted as $s^g$ in Section 2.2) (Benton, 1994; Synodinos, 1990).[17] We test the relative effects of economics and business, assigning them as the reference category so that estimates of the rest of the fields are interpreted as effects relative to economics and business (see Table 1A). The effects of all categories of the academic disciplines on $SO_2$ emissions are negative and significant, indicating that it is reasonable to use business and economics majors as the measure of the academic disciplines that influence the planner to be less aware of environmental issues.

Our instrument is the adolescent fertility rate in the year when a head of state was eighteen years old of which variable name is "adolescent fertility 18". The adolescent fertility rate is the number of birth per 1,000 women ages 15–19 (World Bank, 2015). The adolescent fertility rate in the year when a head of state was eighteen years old was 11.6% in autocratic

38.9%, respectively. In autocratic countries, 57.4% of students, and in democratic countries 45.3% of students enrolled in either business and economics or law and social sciences.

[17] Our hypothesis would be inapplicable if majority of heads of state were educated in economics curriculum with focus on environmental economics as a major subdiscipline. Pearce (2002) describes that the origins of environmental economics lies in the 1950s in historical perspective, which has grown to be a major subdiscipline of economics from the beginning of the 1960s. In our sample, the average birth year of heads of state in autocratic and democratic countries is in the 1940s. It is thus more likely that they were instructed in the curriculum placing an emphasis on the pursuit of economics growth rather than protecting environment.

countries on average, 1.7 times higher than in democratic countries. Note that the adolescent fertility rate of the years our dataset spans is denoted as another variable name, “adolescent fertility”.

We indirectly measure $m^{D}{}_{it}$ (the measure of the proportion of the population participating in the environmental lobby groups in democratic country $i$ at year $t$) using sociodemographic population factors, such as age composition and degree of urbanization as well as civil liberty index created by Freedom House. The index rates how widely countries allow civil liberties with respect to freedoms of expression, assembly, association, education and religion. Farzin and Bond (2006) suggest that age and degree of urbanization play an important role in shifting individuals’ environmental preferences. They show that a younger population tends to demand environmental quality and leads to less production-based emissions (such as $NO_x$, VOC, and $SO_2$) while urbanization can have a mixed effect on environmental quality. Age composition and degree of urbanization are proxied by share of the total population under age 15 and share of the total population living in urban areas (World Bank, 2015).

Following the model, our proxy measures for the number of firms, the price of the dirty good, and the consumers’ income are industrial output as a percentage of gross domestic product (GDP), real interest rate, and GDP growth rate, respectively. The data for these three proxies are from the World Bank (WB). To control for possible effects of institutional quality and regime transitions, we include a state fragility index created by the Integrated Network for Societal Conflict Research (INSCR). We also introduce a variable, birth year of heads of state, collected from the Barcelona Center for International Affairs.

To capture geographic and inherent characteristics, we include forest area as a percentage of the total land area and annual temperature from the WB database, landlocked and number of neighboring countries from the World Factbook, and religion prevalence from multiple sources.[18] Religious prevalence indicates the proportion of population believing in four major religions: Christianity, Buddhism, Islam, and Hinduism. Lastly, the foreign direct investment as a share of GDP is introduced as a control variable from the WB.

## 5. Results

We present three sets of regressions to validate the consistency of inference in our estimations. The first set includes only the variables derived from our theoretical model and the control variables representing the geographical characteristics. The second set of estimations follows more a stringent specification with control variables that reflect additional planner's characteristics, institutional quality of a country, and inherent cultural characteristics. The third set of estimations include all control variables. This specification will be applied for the rest of estimations. Based on our hypothesis, we focus on the academic discipline of business and economics and measure its effect by applying three methods: time fixed effects, OLS, and IV. To increase the reliability of inference, we cluster observations at the state level to obtain robust standard errors.

Tables 2 presents the results measuring the effect of a planner's academic background in business and economics on $SO_2$ emissions in autocratic countries. The estimates are interpreted as effects relative to the rest of the fields. The relative effects of business and economics on $SO_2$

[18]Association of Religion Data Archives, American Religious Identification Survey, Integrated Public Use Microdata Series International, Religions of the World, A Comprehensive Encyclopedia of Beliefs and Practices, World Religion Database, and national censuses.

emissions are positive and significant both with and without year dummies in the first two specifications in our autocratic country sample. The academic discipline coefficients on our pollution indicator variable become smaller when all control variables are included. The magnitude of the coefficient estimates of business and economics is in a range between 0.025 and 0.045. It implies that for a head of state educated in business and economics, $SO_2$ emissions lead to a greater ranging between 0.025 to 0.045 metric tons per capita relative to the case of a head of state educated in the rest of the fields. As expected, in the democratic country sample of Table 3, the relative effects of business and economics are not statistically significant.

In Table 2, we find that the coefficient estimates of a variable representing a planner's characteristics such as birth year are statistically significant in the autocratic country sample. It is positively associated with $SO_2$ emissions in the autocratic sample, implying that the younger a head of state, the more $SO_2$ emissions release. One reason may be that younger government planners tend to develop industrial sectors and initiate grand-scale projects, which result in an increase in $SO_2$ emissions. As the age distribution of the society, as measured by the percentage of the population less than fifteen years of age, is negatively correlated with $SO_2$ emissions in the democratic sample, this result may look contradictory. However, this could partly reflect different environmental preferences across age groups, considering in our sample the average birth year of heads of state in autocratic and democratic countries is in the 1940s.

We apply the IV method to increase the reliability of our estimation results. Table 4 presents the first-stage outcomes measuring the effect of adolescent fertility 18 on business and economics. The estimates are negative and significant both with and without year dummies in the autocratic country sample, implying that heads of state were less likely to be educated in business and economics when the adolescent fertility rate of the year when they were eighteen was higher. These results are statistically significant at the 95% level and indicate that our instrument is not weak. We also conduct a Stock–Yogo test for weak instruments, which shows that our instrument is not weak if we are willing to accept a rejection rate of at most 10% for the Wald test (Baum et al. 2007; Stock and Yogo, 2005).

Table 2. Effect of Business and Economics on $SO_2$ Emissions, Autocracy, OLS and Time Fixed Effects, Specification 1-3

| | (1) | (1-1) | (2) | (2-1) | (3) | (3-1) |
|---|---|---|---|---|---|---|
| Business and economics | 0.045** | 0.044** | 0.028* | 0.025* | 0.015 | 0.012 |
| | (0.018) | (0.017) | (0.015) | (0.014) | (0.013) | (0.012) |
| University | | | -0.003 | -0.001 | -0.009 | -0.007 |
| | | | (0.005) | (0.004) | (0.006) | (0.004) |
| Birth year | | | 0.0003* | 0.0005** | 0.0002 | 0.0004** |
| | | | (0.0002) | (0.0002) | (0.0002) | (0.0002) |
| Industry | 0.0002 | 0.0002* | 0.00008 | 0.0002 | 0.0001 | 0.0002 |
| | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) |
| GDP growth | 0.0002 | 0.0003 | 0.00007 | 0.0002 | -0.0001 | 0.00002 |
| | (0.0005) | (0.0004) | (0.0003) | (0.0003) | (0.0002) | (0.0002) |
| Interest rate | 0.0001 | 0.0001 | 0.0001 | 0.0002* | 0.00004 | 0.00009* |
| | (0.00009) | (0.00008) | (0.0001) | (0.0001) | (0.00006) | (0.00005) |
| FDI net inflow | | | | | 0.00006 | 0.00008 |
| | | | | | (0.0002) | (0.0002) |
| Fragility | | | | | -0.002** | -0.002** |
| | | | | | (0.0009) | (0.0008) |
| Forest area | 0.00003 | 0.00001 | -0.0001 | -0.0002* | -0.0001 | -0.0001 |
| | (0.00008) | (0.00009) | (0.0001) | (0.00009) | (0.0001) | (0.0001) |
| Temperature | -0.002*** | -0.002*** | -0.002*** | -0.002*** | -0.001*** | -0.001*** |
| | (0.0004) | (0.0004) | (0.0004) | (0.0004) | (0.0003) | (0.0003) |
| Landlocked | -0.010* | -0.009 | -0.010 | -0.011* | -0.002 | -0.003 |
| | (0.006) | (0.006) | (0.006) | (0.005) | (0.005) | (0.005) |
| Land neighbors | -0.003*** | -0.003*** | -0.004** | -0.003*** | -0.002*** | -0.002*** |
| | (0.0009) | (0.0009) | (0.001) | (0.001) | (0.0007) | (0.0007) |
| Christianity | | | -0.016 | -0.012 | 0.002 | -0.0007 |
| | | | (0.040) | (0.034) | (0.026) | (0.025) |
| Islam | | | -0.029 | -0.025 | -0.018 | -0.018 |
| | | | (0.031) | (0.027) | (0.019) | (0.019) |
| Buddhism | | | -0.003 | 0.009 | -0.013 | -0.015 |
| | | | (0.074) | (0.063) | (0.051) | (0.051) |
| Hinduism | | | 0.183 | 0.186 | 0.083 | 0.066 |
| | | | (0.176) | (0.176) | (0.157) | (0.163) |
| Year dummy | No | Yes | No | Yes | No | Yes |
| N | 221 | 221 | 210 | 210 | 172 | 172 |
| adj. R-sq | 0.573 | 0.573 | 0.644 | 0.667 | 0.652 | 0.670 |

Notes: Clustered standard errors in parentheses. * p<0.1 ** p<0.05 *** p<0.01

Table 3. Effect of Business and Economics on $SO_2$ Emissions, Democracy, OLS and Time Fixed Effects, Specification 1-3

| | (1) | (1-1) | (2) | (2-1) | (3) | (3-1) |
|---|---|---|---|---|---|---|
| Business and economics | -0.0007 | 0.0003 | 0.0007 | 0.001 | 0.004 | 0.006 |
| | (0.007) | (0.007) | (0.007) | (0.007) | (0.006) | (0.006) |
| Birth year | | | -0.0003 | -0.0002 | -0.0002 | 0.00007 |
| | | | (0.0003) | (0.0003) | (0.0003) | (0.0003) |
| Industry | 0.0002 | 0.0002 | 0.00007 | 0.00001 | -0.0002 | -0.0004 |
| | (0.0004) | (0.0004) | (0.0004) | (0.0004) | (0.0005) | (0.0005) |
| GDP growth | 0.0004 | 0.0005 | 0.0006 | 0.0007* | 0.0008 | 0.001** |
| | (0.0004) | (0.0004) | (0.0004) | (0.0004) | (0.0005) | (0.0005) |
| Interest rate | 0.00007 | -0.000001 | -0.000007 | -0.00006 | 0.0000001 | -0.00007 |
| | (0.0002) | (0.0002) | (0.0002) | (0.0002) | (0.0002) | (0.0002) |
| Civil liberty | -0.008 | -0.010 | -0.004 | -0.006 | -0.007 | -0.011* |
| | (0.007) | (0.007) | (0.005) | (0.005) | (0.006) | (0.006) |
| Ages 0–14 | -0.0008 | -0.0007 | -0.002* | -0.001* | -0.002* | -0.002* |
| | (0.0006) | (0.0006) | (0.0008) | (0.0007) | (0.001) | (0.0009) |
| Urbanization | | | | | 0.0004 | 0.0005 |
| | | | | | (0.0003) | (0.0003) |
| FDI net inflow | | | | | -0.0007* | -0.0008** |
| | | | | | (0.0003) | (0.0003) |
| Fragility | | | | | 0.002 | 0.002 |
| | | | | | (0.001) | (0.001) |
| Forest area | -0.0002 | -0.0002 | -0.0002 | -0.0002 | -0.0003* | -0.0002 |
| | (0.0002) | (0.0002) | (0.0002) | (0.0002) | (0.0002) | (0.0002) |
| Temperature | 0.001 | 0.001 | 0.002 | 0.002 | 0.001 | 0.002 |
| | (0.001) | (0.001) | (0.002) | (0.002) | (0.001) | (0.001) |
| Landlocked | -0.003 | -0.003 | -0.002 | -0.004 | 0.0009 | 0.00007 |
| | (0.008) | (0.008) | (0.008) | (0.008) | (0.010) | (0.010) |
| Land neighbors | -0.0008 | -0.0008 | -0.002 | -0.002 | -0.002 | -0.002 |
| | (0.001) | (0.001) | (0.002) | (0.002) | (0.002) | (0.001) |
| Christianity | | | 0.030 | 0.030 | 0.055 | 0.063* |
| | | | (0.033) | (0.034) | (0.033) | (0.033) |
| Islam | | | 0.004 | 0.008 | 0.037 | 0.056 |
| | | | (0.036) | (0.035) | (0.042) | (0.043) |
| Buddhism | | | -0.006 | -0.004 | 0.026 | 0.043 |
| | | | (0.042) | (0.042) | (0.044) | (0.044) |
| Hinduism | | | 0.008 | 0.007 | 0.036 | 0.046 |
| | | | (0.034) | (0.034) | (0.038) | (0.038) |
| Year dummy | No | Yes | No | Yes | No | Yes |
| N | 284 | 284 | 284 | 284 | 272 | 272 |
| adj. R-sq | 0.170 | 0.178 | 0.254 | 0.249 | 0.295 | 0.315 |

Notes: Clustered standard errors in parentheses. * p<0.1 ** p<0.05 *** p<0.01

Table 4. Effect of Adolescent Fertility Rate 18 on Business and Economics, First Stage, Autocracy vs. Democracy, OLS and Time Fixed Effects

| | Autocracy | | Democracy | |
|---|---|---|---|---|
| Adolescent fertility 18 | -0.001* | -0.002** | -0.003 | -0.002 |
| | (0.0008) | (0.0007) | (0.003) | (0.003) |
| University | 0.103 | 0.091 | | |
| | (0.123) | (0.133) | | |
| Birth year | -0.007 | -0.007 | -0.022* | -0.020* |
| | (0.005) | (0.005) | (0.012) | (0.012) |
| Industry | -0.007** | -0.006* | 0.007 | 0.006 |
| | (0.003) | (0.003) | (0.008) | (0.008) |
| GDP growth | 0.002 | 0.0009 | -0.012 | -0.005 |
| | (0.002) | (0.003) | (0.010) | (0.012) |
| Interest rate | 0.0009 | 0.001 | -0.005 | -0.005 |
| | (0.002) | (0.003) | (0.005) | (0.006) |
| Civil liberty | | | -0.151 | -0.162 |
| | | | (0.104) | (0.111) |
| Ages 0–14 | | | 0.003 | 0.003 |
| | | | (0.019) | (0.019) |
| Urbanization | | | -0.005 | -0.005 |
| | | | (0.004) | (0.004) |
| FDI net inflow | -0.002 | -0.001 | 0.004 | 0.005 |
| | (0.002) | (0.003) | (0.004) | (0.004) |
| Fragility | 0.005 | 0.005 | 0.027 | 0.029 |
| | (0.014) | (0.016) | (0.026) | (0.027) |
| Forest area | 0.015*** | 0.015*** | -0.001 | -0.002 |
| | (0.004) | (0.004) | (0.004) | (0.004) |
| Temperature | 0.016** | 0.017** | -0.005 | -0.005 |
| | (0.007) | (0.007) | (0.015) | (0.016) |
| Landlocked | -0.096 | -0.101 | 0.209 | 0.221 |
| | (0.101) | (0.107) | (0.236) | (0.234) |
| Land neighbors | 0.0004 | 0.004 | -0.020 | -0.018 |
| | (0.022) | (0.024) | (0.038) | (0.039) |
| Christianity | -0.231 | -0.207 | 0.560 | 0.528 |
| | (0.512) | (0.563) | (0.353) | (0.343) |
| Islam | 0.291 | 0.321 | 0.528 | 0.506 |
| | (0.386) | (0.422) | (0.473) | (0.474) |
| Buddhism | -0.663 | -0.667 | 0.576 | 0.554 |
| | (0.544) | (0.611) | (0.478) | (0.496) |
| Hinduism | 0.513 | 0.651 | -6.304* | -6.276 |
| | (1.758) | (1.790) | (3.653) | (3.828) |
| Year dummy | No | Yes | No | Yes |
| N | 194 | 194 | 285 | 285 |
| adj. R-sq | 0.392 | 0.356 | 0.179 | 0.159 |

Notes: Clustered standard errors in parentheses. * p<0.1 ** p<0.05 *** p<0.01

Table 5. Effect of Business and Economics on $SO_2$ Emissions, IV Instrumenting Business and Economics, Autocracy vs. Democracy

| | Autocracy | | Democracy | |
|---|---|---|---|---|
| Business and economics | 0.020*** | 0.022*** | -0.023 | -0.027 |
| | (0.006) | (0.006) | (0.028) | (0.029) |
| University | -0.042*** | -0.046*** | | |
| | (0.011) | (0.012) | | |
| Birth year | 0.001*** | 0.001*** | -0.002 | -0.002 |
| | (0.0004) | (0.0004) | (0.002) | (0.002) |
| Industry | 0.0007*** | 0.0007*** | 0.0005 | 0.0005 |
| | (0.0002) | (0.0002) | (0.0006) | (0.0006) |
| GDP growth | -0.0002 | 0.00003 | 0.0009 | 0.001 |
| | (0.0001) | (0.0002) | (0.0008) | (0.001) |
| Interest rate | 0.00005*** | 0.000003 | 0.0004 | 0.0003 |
| | (0.00001) | (0.00003) | (0.0006) | (0.0007) |
| Civil liberty | | | -0.004 | -0.005 |
| | | | (0.005) | (0.006) |
| Ages 0–14 | | | -0.002* | -0.002* |
| | | | (0.001) | (0.001) |
| Urbanization | | | -0.0006 | -0.0006 |
| | | | (0.0004) | (0.0005) |
| FDI net inflow | -0.0001 | -0.00009 | -0.00005 | 0.00006 |
| | (0.00008) | (0.00009) | (0.0004) | (0.0005) |
| Fragility | -0.0004 | -0.0004 | 0.002 | 0.002 |
| | (0.0004) | (0.0005) | (0.002) | (0.002) |
| Forest area | -0.0005*** | -0.0005*** | -0.0003 | -0.0003 |
| | (0.0001) | (0.0002) | (0.0002) | (0.0002) |
| Temperature | -0.002*** | -0.001*** | 0.0008 | 0.0009 |
| | (0.0001) | (0.00008) | (0.0008) | (0.0008) |
| Landlocked | -0.007 | -0.007 | -0.004 | -0.002 |
| | (0.004) | (0.005) | (0.014) | (0.015) |
| Land neighbors | 0.005** | 0.006** | -0.001 | -0.001 |
| | (0.002) | (0.002) | (0.002) | (0.002) |
| Christianity | 0.139*** | 0.152*** | -0.008 | -0.009 |
| | (0.042) | (0.047) | (0.033) | (0.034) |
| Islam | 0.090*** | 0.103*** | -0.056 | -0.057 |
| | (0.032) | (0.033) | (0.040) | (0.043) |
| Buddhism | 0.324*** | 0.354*** | -0.064 | -0.067 |
| | (0.097) | (0.102) | (0.040) | (0.043) |
| Hinduism | 0.507*** | 0.562*** | -0.378 | -0.460 |
| | (0.105) | (0.112) | (0.319) | (0.312) |
| Year dummy | No | Yes | No | Yes |
| N | 62 | 62 | 175 | 175 |
| adj. R-sq | 0.956 | 0.959 | -0.342 | -0.614 |
| Wald F-statistics | $57.773^{+}$ | $38.399^{+}$ | 1.835 | 1.979 |

Notes: (1) Clustered standard errors in parentheses; * p<0.1 ** p<0.05 *** p<0.01.
(2) $^{+}$ statistically significant when allowing for 10% rejection rate.
(3) The critical values for the Kleibergen–Paap rk Wald *F*-statistic at the 10%, 15%, 20%, and 25% maximal IV size for the just-identified case are 16.38, 8.96, 6.66, and 5.53, respectively.

Table 5 presents the effect of a planner's academic background in business and economics on $SO_2$ emissions after instrumenting. We find significant and consistent results that a head of state's education in business and economics leads to an increase in $SO_2$ emissions of 0.020–0.022 metric tons per capita. The business and economics coefficients after instrumenting are close to the range of estimates generated from the time fixed effects and OLS models. One issue we face is that the number of observations drops considerably, to 62, with only 13 of 23 autocratic countries remaining. To verify that the dropped observations are random, we compare the signs and significance of the estimates of the rest of the variables (not the geographic and inherent variables) to their counterparts generated from the OLS estimation. It appears that the signs are all consistent when comparing significant variables in both estimations.

We conclude that a head of state's education in business and economics negatively affects environmental quality relative to heads of state educated in other fields in countries under autocratic regimes, but this implication is not applicable to democratic countries.

## 6. Summary and Conclusion

This article investigates how a government planner's educational background impacts environmental outcomes in autocratic regimes. We model that the planner's educational background plays a critical role in determining the stringency of environmental regulations in the process of policy formation. Our model shows that less-stringent environmental regulation is implemented in an autocratic regime if the planner is educated in an academic discipline that influences one to be less conscious of environmental damages. However, in democratic regimes, regulatory stringency is also subject to influence from lobbying.

We test the result by estimating the effect of university majors of heads of state—a proxy of academic background—on $SO_2$ emissions. Our empirical findings indicate that for heads of states educated in economics and business, $SO_2$ emissions more increase by 0.020–0.045 metric tons per capita relative to heads of state educated in another discipline. These estimation results are consistent across the specifications and models when using the autocratic country sample, while the relative negative effect of discipline disappears in the democratic country sample.

We suggest that the academic background of a government planner is an important factor determining the stringency of environmental policies and, therefore, pollution emissions. However, this mechanism does not function in democratic countries, where citizens exercise power and elect representatives. This information is useful to understand the underlying mechanism for implementing environmental policies in autocratic countries, currently regarded as major contributors to air pollution.

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**Appendices**

Appendix A. Proofs for the Theoretical Model

The first-order conditions of equation (2) with respect to $x_i$ and $h_i$ yield

(A1) $$\frac{\partial \pi^i}{\partial x_i} = p^* - V_x - \tau\theta(h_i) = 0,$$

(A2) $$\frac{\partial \pi^i}{\partial h_i} = -V_h - \tau\theta_h x_i = 0.$$

Equation (A1) states that firm $i$ produces good $x$ up to the point where its output price equals the marginal cost net of tax. Equation (A2) states that it equates the marginal cost of investing in abatement technology to the marginal gain of lowering the pollution tax. The equilibrium values of $x_i$ and $h_i$ are defined as functions of $\tau$ and $p^*$: $x_i(\tau, p^*)$ and $h_i(\tau, p^*)$. Applying the implicit function theorem to equations (A1) and (A2), $\frac{\partial x_i}{\partial \tau} = \frac{-\theta}{V_{hh}} < 0$ and $\frac{\partial h_i}{\partial \tau} = \frac{-\theta_h x_i}{V_{hh}+\tau\theta_{hh}x_i} > 0$ are derived, respectively. An increase in the pollution tax rate will decrease output and increase spending on abatement technology. The profit function in equilibrium is $\pi^*\big(x^*(\tau, p^*), h^*(\tau, p^*)\big)$.

Table 1A. Effects of Academic Disciplines on $SO_2$ Emissions, Autocracy vs. Democracy, Time Fixed Effects

| | Autocracy | | Democracy | |
|---|---|---|---|---|
| STEM and health | -0.016*** | -0.016 | -0.002 | -0.002 |
| | (0.006) | (0.012) | (0.007) | (0.012) |
| Law and social science | -0.010* | -0.010 | -0.005 | -0.005 |
| | (0.005) | (0.011) | (0.003) | (0.006) |
| Humanities | -0.015** | -0.015 | -0.017** | -0.017 |
| | (0.006) | (0.011) | (0.007) | (0.016) |
| Military academy | -0.002 | -0.002 | -0.009 | -0.009 |
| | (0.005) | (0.010) | (0.006) | (0.010) |
| University | -0.0002 | -0.0002 | | |
| | (0.006) | (0.012) | | |
| Birth year | 0.0004*** | 0.0004** | 0.00006 | 0.00006 |
| | (0.00009) | (0.0002) | (0.0002) | (0.0003) |
| Industry | 0.00009 | 0.00009 | -0.0003 | -0.0003 |
| | (0.00006) | (0.0001) | (0.0003) | (0.0006) |
| GDP growth | 0.0001 | 0.0001 | 0.001** | 0.001* |
| | (0.0003) | (0.0002) | (0.0004) | (0.0005) |
| Interest rate | 0.00006** | 0.00006 | -0.00005 | -0.00005 |
| | (0.00003) | (0.00005) | (0.0001) | (0.0002) |
| Civil liberty | | | -0.011*** | -0.011* |
| | | | (0.003) | (0.006) |
| Ages 0–14 | | | -0.002*** | -0.002* |
| | | | (0.0005) | (0.001) |
| Urbanization | | | 0.0005*** | 0.0005 |
| | | | (0.0002) | (0.0003) |
| FDI net inflow | 0.0001 | 0.0001 | -0.0008*** | -0.0008** |
| | (0.0002) | (0.0003) | (0.0003) | (0.0003) |
| Fragility | -0.002*** | -0.002* | 0.002*** | 0.002 |
| | (0.0005) | (0.001) | (0.0007) | (0.002) |
| Forest area | -0.00006 | -0.00006 | -0.0003*** | -0.0003 |
| | (0.00005) | (0.0001) | (0.00008) | (0.0002) |
| Temperature | -0.001*** | -0.001** | 0.002** | 0.002 |
| | (0.0002) | (0.0004) | (0.0006) | (0.002) |
| Landlocked | 0.0005 | 0.0005 | -0.0006 | -0.0006 |
| | (0.003) | (0.006) | (0.00480) | (0.010) |
| Land neighbors | -0.002*** | -0.002* | -0.002*** | -0.002 |
| | (0.0005) | (0.0009) | (0.0006) | (0.001) |
| Christianity | -0.004 | -0.004 | 0.062*** | 0.062* |
| | (0.016) | (0.034) | (0.019) | (0.035) |
| Islam | -0.022* | -0.022 | 0.054** | 0.054 |
| | (0.012) | (0.025) | (0.025) | (0.044) |
| Buddhism | -0.010 | -0.010 | 0.040 | 0.040 |
| | (0.025) | (0.049) | (0.026) | (0.047) |
| Hinduism | 0.101 | 0.101 | 0.044* | 0.044 |
| | (0.074) | (0.157) | (0.022) | (0.040) |
| Clustering | No | Yes | No | Yes |
| Year dummies | Yes | Yes | Yes | Yes |
| N | 172 | 172 | 272 | 272 |
| adj. $R^2$ | 0.702 | 0.702 | 0.310 | 0.310 |

Notes: Robust standard errors in parentheses. * p<0.1 ** p<0.05 *** p<0.01

Table 2A. Data Definition and Sources

| Variable | Description | Source |
|---|---|---|
| $SO_2$ | $SO_2$ emissions (metric ton)/capita | NASA Socioeconomic Data and Applications Center (SEDAC) |
| STEM and health | 1 = STEM or health majors, 0 = otherwise | Barcelona Center for International Affairs |
| Business and economics | 1 = business or economics majors, 0 = otherwise | Barcelona Center for International Affairs |
| Law and social sciences | 1 = law or social sciences majors, 0 = otherwise | Barcelona Center for International Affairs |
| Humanities | 1 = humanities majors, 0 = otherwise | Barcelona Center for International Affairs |
| Academic military | 1 = military academy, 0 = otherwise | Barcelona Center for International Affairs |
| Adolescent fertility | Births per 1,000 women ages 15–19 | World Bank (WB) Indicator |
| University | 1 = holds university degree, 0 = otherwise | |
| Birth year | Birth year of a head of state | Barcelona Center for International Affairs |
| GDP growth | GDP growth rate (%) | WB Indicator |
| Lending rate | Lending interest rate (%) | WB Indicator |
| Industry | Industry, value added (% of GDP) | WB Indicator |
| FDI net inflow | Foreign direct investment, net inflows (% of GDP) | WB Indicator |
| Fragility | State fragility index<br>0 (no fragility), 25 (extreme fragility) | Integrated Network for Societal Conflict Research |
| Civil liberty | 1 (wide range of civil liberties), 7 (no civil liberties) | Freedom House |
| Forest area | % of land | WB Indicator |
| Temperature | Degrees Celsius | WB Climate Change Knowledge Portal |
| Christian | Proportion of population practicing Christianity | |
| Islam | Proportion of population practicing Islam | |
| Buddhism | Proportion of population practicing Buddhism | |
| Hinduism | Proportion of population practicing Hinduism | |
| Landlocked | 1 = landlocked country, 0 = otherwise | World Factbook |
| Land neighbors | Number of land neighbors | World Factbook |
| Ages 0–14 | Population ages 0–14 (% of total) | WB Indicator |
| Urbanization | Population in urban areas | WB Indicator |

Appendix B. List of Countries by Regime

Autocratic Countries

China, Singapore, Azerbaijan, Peru, Malaysia, Mexico, Russian Federation, Qatar, Senegal, Vietnam, Tanzania, Egypt, Algeria, Angola, Cameron, Congo, Rep, Ethiopia, Kenya, Libya, Myanmar, Mozambique, Syrian Arab Republic, Zimbabwe

Democratic Countries

Albania, Austria, Belgium, Croatia, Denmark, Finland, South Africa, Chile, Argentina, Brazil, Peru, Venezuela, Japan, Thailand, Australia, New Zealand, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Uruguay, Colombia, Costa Rica, Mexico, United Kingdom, United States, Spain, Sweden, Ecuador, Guatemala, India, Indonesia, Honduras, Philippines, Paraguay, Sri Lanka, Slovak Republic, Slovenia, Kenya, Nigeria

Notes: Peru, Mexico, and Kenya are overlapped in autocratic and democratic countries because they experienced a regime change during the period our dataset spans.

CHAPTER FOUR

# MODELING THE ECONOMIC IMPACT OF THE TRADE REGULATION OF INVASIVE SPECIES: A STUDY OF APPLE PRODUCTION UNDER AN APPLE MAGGOT QUARANTINE PROGRAM


## Abstract

Agricultural phytosanitary trade regulations exert an impact on U.S. producers' economic profits. We examine the phytosanitary trade regulations related to apple maggot and its impact on Washington apple producers' profitability in association with the exports of apples produced in apple maggot quarantine areas. We develop a representative producer's management problem to choose an optimal pesticide use and find a positive relationship between the number of pesticide applications and the export costs due to phytosanitary trade regulations. We estimate a producer's profits for apples produced in areas under different apple maggot quarantine status (pest-free, quarantine) by the existence of a phytosanitary trade regulation requiring an additional cold storage period, as required by strategic commercial partners, China and British Columbia (Canada). If a producer has an orchard within a quarantine area and exports 2% of total yield to China and British Columbia, his or her profit is approximately lower by $185 per acre compared to producers not exporting products to these two markets. If the share of the yield shipped to the two markets rises to 5%, profits will decrease by $4,881 per acre compared to producers not exporting to the two markets.

## 1. Introduction

Agricultural phytosanitary trade regulations of invasive species are designed to prevent the introduction of alien species considered harmful to the domestic agricultural industry (USDA, 2017). Common practices for preventing the risk of invasion include cleaning a cargo hold, sterilizing the soil in which the product is shipped, and establishing inspection requirements for imported agricultural products, among others (Corn and Johnson, 2013). Such regulations necessarily increase the cost burden to producers and have the potential to reduce trading volumes (Disdier et al., 2008).

The emergence of transnational agricultural organizations coupled with globalized production and distribution systems, and the proliferation of free trade agreements have encouraged the existence of global agricultural markets (Bruinsma, 2003). Global agricultural markets have opened opportunities for the United States (U.S.) apple producers to expand their businesses beyond the saturated domestic market, increasing the export dependency for the apple industry. In 2015, the U.S. exported 988.5 thousand tons of apples out of the total production 5.02 million tons (19.7%) (UN Comtrade 2016, USDA NASS, 2017). Notably, the state of Washington—the top apple-producing state in the U.S.—exported more than 30% of its total production during the same marketing year (WSTFA, 2016). The growth of world trade has had a number of environmental consequences, of which the most significant may well be the redistribution of pests (Perrings et al. 2010). The opening of new markets or trade routes has resulted in the introduction of new species either as the object of trade or as the unintended consequence of trade. Indeed, the volume and direction of trade turn out to be good empirical predictors of invasions (Levine and D'Antonio 2003).

Among the pests affected by trade regulations, the North American apple maggot (*Rhagoletis pomonella*) has received considerable attention by both producers and regulators for the following reasons: its invasiveness, the bioclimatic similarity between trading partners, and the volume and composition of trade. In 1970's, the apple maggot was regarded as a serious pest in the U.S., distributing over the eastern half of the continent as well as threatening the northwestern regions (Niazee and Penrose, 1981). The pest has been currently under control along with applications of effective pesticides, but it is regaining the attention due to the introduction of phytosanitary regulations by importing regions. Apple maggot attacks apples, cherries, plums, apricots, and pears (Boller and Prokopy, 1976). The main damage is caused by the female fly laying eggs beneath the surface of the host fruit, leaving a puncture wound that results in a sunken spot on the fruit surface. The hatched young larva consumes the flesh of the fruit, leaving a brown trail of rotting flesh and exit holes (Dean and Chapman, 1973). As the damaged fruit usually drops prematurely, orchards infested by apple maggot without a proper treatment could face considerable yield loss (Glass and Lienk, 1971; Howitt, 1993; Sansford et al., 2016).

Washington has implemented a quarantine program to prevent apple maggot dissemination and establishment beyond quarantine areas.[19] Apple producers with orchards in the quarantine areas must comply with pest regulations to export fresh apples (Klaus, 2015). These regulations depend on shipping destinations. For example, China and British Columbia (BC), Canada (both important export markets for Washington State apple operations) require all apples

[19] The apple maggot quarantine areas are where the pest is considered established but officially being controlled.

shipped from the U.S. to be certified as coming from an apple maggot free area. In addition, if apples come from quarantine areas, they must be stored at 1℃ for an additional 40 days.

Recently, concerns about the risk of apple-maggot dissemination and establishment beyond Washington State quarantine areas have increased because compost processing companies have been established in Eastern Washington, increasing the transportation of yard (green) compost waste from the Seattle metropolitan areas, which are apple maggot quarantined, to the eastern parts of Washington, which are apple maggot free. This unprocessed compost has increased the risk of apple-maggot infestation in areas that are apple maggot free and where the bulk of the Washington apple production industry is concentrated (Sansford et al., 2016).

In this framework, we investigate how phytosanitary regulations affect the optimal pest control strategy (in terms of a number of pesticide applications) for an apple producer under the pest quarantine program and assess its impact on profits. We first develop a representative producer's optimal management problem in a theoretical framework where the producer's objective is to maximize profits by choosing an optimal control strategy. We consider situations where the producer's orchard is located in a quarantine or pest-free area. The pest infestation level and the related costs differ according to the area's quarantine status. Based on the model, we examine how the producer's optimal choice changes according to the area's quarantine status and the existence of trade regulation of invasive species on fresh apples shipped from quarantine areas. Finally, we analyze the sensitivity of producer's profits with respect to increases in trade dependency on the export markets imposing the regulation.

This study contributes to the literature on the economic consequences of phytosanitary regulations and producing regions under quarantine programs (Perrings et al., 2010). Phytosanitary regulations are a primary means of reducing the potential risk of biological invasion from international trade and preventing ecological and economic damages that arise when invasive species become established (Olson, 2006). In the existence of such regulation, loss of apple maggot free status would lead to a significant increase in exporting costs and forgone exporting opportunities (Zhao et al., 2007). Krissoff et al. (1997) estimate the impact of the technical barrier to trade by examining a requirement of cold treatment in Mexico and find that the impact is equivalent to a 20–30% tariff, implying that U.S. apple producers' welfare would be affected. Zhao et al. (2007) conduct a welfare analysis of the impact of the apple maggot's prevention program on Washington state producers. Authors simulate different apple-maggot spread rates and show that producers' welfare will decrease as apple maggot continues to spread. Moreover, a 10% reduction in the spread rate will bring additional $1.52 million in benefits to producers. Past studies do not offer an analysis of how a producer responds to a potential increase in the risk of apple maggot infestation and the effects on the producers' profitability given the phytosanitary barriers to trade. Furthermore, we contribute to existing literature by calibrating our model using unique apple-maggot data collected from 9,832 sites across the state of Washington to account for apple-maggot population dynamics.

We use an optimal control model in which a producer chooses a rate of pesticide application subject to insect population dynamics. A producer faces different initial infestation level and might be subject to a trade regulation on invasive species, depending on the location of his/her orchard (e.g., in a quarantine or pest-free area). We show that at the steady state, the phytosanitary trade regulation causing additional storage cost leads to increased rate of pesticide applications. To test the theoretical results, we use our empirically calibrated model to conduct simulations under four scenarios varying by quarantine status (pest-free, quarantine) and the existence of the phytosanitary regulations requiring additional cold storage period. To calibrate the model, we use seven years' data (2009–2015) on yield, cost, and price of 'Red Delicious' apples and the number of apple maggots caught in traps placed by the Washington State Department of Agriculture (WSDA).

We find that an increasing cost burden for the additional cold storage period of 40 days to export fresh apples from quarantine areas to BC (Canada) and China, raises the number of chemical applications. If a producer has an orchard in an apple maggot quarantine area and exports 2% of the total yield to BC and China, he or she will suffer a profit loss of $185/acre (3%) compared to the profits of a producer not exporting products to the two markets. If the unit storage cost increases by 10%, the resulting loss amounts to $1,600/acre relative to the profits made without dependency on the two regulated export markets. Furthermore, the additional storage cost implies a delay in shipments and a decline in market prices and, consequently, profits. If the portion of 'Red Delicious' apples shipped to BC and China out of total yield rises to 5%, profits will decrease by $4,881/acre (85%) compared to the case of not exporting to the two regulated export markets.

This study is organized in the following manner: Section 2 describes theoretical framework. Based on the framework, Section 3 outlines the empirical model and describes the data and parameter values. Section 4 interprets the simulation results. Section 5 concludes.

## 2. Theoretical Framework

We develop an economic model that formalizes a representative fruit producer's management decision to control invasive species. The producer chooses the level of insect control to maximize the net present value of fruit production. The control variable is the rate of pesticide application $u_t$ measured per unit area at time $t$. The state variable is insect population

$g_t^i$ per unit area at time $t$ for $i = \{q, n\}$, where $i$ is the area where the orchard is located, $q$ denotes a quarantine area, and $n$ denotes a pest-free area. The pesticide applications deter the growth of the insect population. Thus, the net growth rate of the insect stocks $G(g_t^i)$ from $t$ to $t + 1$ is defined as a function of current stock level $g_t^i$, net of the rate of stock eradication by pesticide applications $\omega u_t g_t^i$, where $\omega$ is the mortality rate of the pesticide, which is a constant.

Producer revenues depend on fruit yield $Y_t$ and prices. A producer receives a high price $p_t^h$ for non-infested fruits and a low price $p_t^l$ for infested fruits. Total production costs depend on the rate of pesticide applications $u_t$, the size of the existing insect population $g_t^i$, and additional storage costs $S_t^i$ for $i = \{q, n\}$. Production costs rise as more pesticide is applied. These costs, $C(\cdot)$, are an increasing function of $u_t$ (i.e., $C_u > 0$). We assume that $C_g$ is positive (i.e., $C_g > 0$). The storage costs are conditioned on an exogenous phytosanitary trade regulation $R$ imposed by export countries on fruits shipped from quarantine areas. For simplicity's sake, we make a few more assumptions as follows: $C_{us}, C_{uu}$, and $C_{gg} = 0$.

We solve the optimal pesticide application problem for a fruit producer with an orchard in area $i = \{q, n\}$ by maximizing the following expected profits function:

$$(1) \qquad \max_{u_t \geq 0} \int_0^\infty e^{-\rho t} \left[ \underbrace{p_t^h Y_t \theta(g_t^i) + p_t^l Y_t \left(1 - \theta(g_t^i)\right)}_{(a)} - C(u_t, g_t^i, S_t^i | R) \right] dt,$$

where $e^{-\rho t}$ is a discount factor with discount rate $\rho$ and $\theta(g_t^i)$ denotes the probability that the fruit is not infested by $g_t^i$ at time $t$. It is a convex decreasing function of the insect population (i.e., $\theta_g < 0$ and $\theta_{gg} > 0$). The transversality condition is $\lim_{t \to \infty} e^{-\rho t} \lambda_t g_t^i = 0$, where $\lambda_t$ is a co-state variable expressed in units of current-value net benefits associated with the insect population at time $t$, a shadow price for the insect population. The term $p_t^h Y_t$ measures revenues from selling non-infested fruits at the high market price $p_t^h$, while the term $p_t^l Y_t$ measures revenues from selling infested fruits at the low market price $p_t^l$. Hence, the term $(a)$ represents a producer's expected revenues at time $t$ from selling both non-infested and infested fruits. Storage costs are applicable only for fresh apples shipped from quarantine areas (i.e., $S_t^q|(R=1)>0$ and $S_t^n|(R=0)=0$). The problem is subject to the insect population equation of motion:

(2) $$\dot{g}^i = G\left(g_t^i\right) - \omega u_t g_t^i, \qquad t = 0, 1, \dots, T-1,$$

where $g_t^i$ is insect population in area $i = \{q, n\}$ at time $t$. The second term of equation (2) is the kill function that measures insect mortality due to pesticide application (Marsh et al., 2000). The initial value of the state variable is specified as $g_0 = g^o$.

We construct the current-value Hamiltonian of a producer's problem to characterize the optimal control using Pontryagin's Maximum Principle:

(3) $$H \equiv p_t^h Y_t \theta\left(g_t^i\right) + p_t^l Y_t \left(1 - \theta\left(g_t^i\right)\right) - C\left(u_t, g_t^i, S_t^i \middle| R\right) + \lambda_t\left(G\left(g_t^i\right) - \omega u_t g_t^i\right).$$

Ignoring the time subscripts for simplicity, the necessary conditions for a maximum are:

(4) $$\partial H / \partial u = 0 \Leftrightarrow C_u + \lambda \omega g^i = 0.$$

(5) $$\dot{\lambda} = -\partial H / \partial g + \rho\lambda \Leftrightarrow \dot{\lambda} = \rho\lambda - (p^h - p^l) Y \theta_g + C_g - \lambda G_g + \lambda \omega u.$$

(6) $$\dot{g^\iota} = G\left(g^i\right) - \omega u_t g^i.$$

In the maximum principle condition (equation 4), the term $\lambda \omega g^i$ represents the value of the marginal benefits from decreasing one unit of the insect population. That is, the condition describes that the marginal cost of insect control should be equal to the value of the marginal benefits from decreasing an additional unit of the insect population. The shadow price $\lambda_t$ interpreted as a marginal benefit of preserving the insect stock is negative so that there exists an interior solution. The condition ruling the behavior of the shadow price over time (equation 5) can be written with the proportionate rate of change of the shadow price on the left side: $\frac{\dot{\lambda}}{\lambda} = \rho - \frac{(p^h - p^l)Y\theta_g}{\lambda} + \frac{C_g}{\lambda} - G_g + \omega u$. The rate of change of the net benefits from controlling the insect population should be higher when the total costs depend upon the size of the insect population given $C_g > 0$ and the benefits from selling non-infested fruits increase.

Our interest is in evaluating the effect of storage cost $S_t^i$, exogenously determined by phytosanitary trade regulation $R$, on the rate of pesticide application $u_t$ at the steady state: $du_t/dS_t^i$ . First, differentiating equation (4) with respect to time yields:

(7) $$C_{uu}\dot{u} + C_{ug}\dot{g} + \dot{\lambda}\omega g^i + \lambda\omega\dot{g}^i = 0.$$

Next, by combining equation (7) and (5) we obtain:

(8) $$C_{uu}\dot{u} + C_{ug}\dot{g} + \left[\rho\lambda - (p^h - p^l)Y\theta_g + C_g - \lambda(G_g - \omega u)\right]\omega g^i + \lambda\omega\dot{g}^i = 0.$$

From equation (4), we know that $\lambda = -C_u/\omega g^i$, so equation (8) can be re-written as:

(9) $$C_{uu}\dot{u} + C_{ug}\dot{g} + \left[-\rho \, {}^{C_u}\!/_{\omega g^i} - (p^h - p^l)Y\theta_g + C_g + (G_g - \omega u) \, {}^{C_u}\!/_{\omega g^i}\right]\omega g^i - C_u \, {}^{\dot{g}^i}\!/_{g^i} = 0.$$

We use equations (6) and (9) for comparative statics between $S_t^i$ and $u_t$ at the steady state, when all variables are unchanging with respect to time, so $\dot{u}$ and $\dot{g}$ are equal to 0. Thus, at the steady state, equations (6) and (9) are:

(10) $$\left(C_g - p^d Y\theta_g\right)\omega g^i - (\rho + \omega u - G_g)C_u = 0, \text{ where } p^d = (p^h - p^l).$$

(11) $$G\left(g^i\right) - \omega u g^i = 0.$$

We take the total derivative with respect to $S_t^i$ for both equations and apply Cramer's rule (see Appendix). Given the assumptions we make, the following equation is obtained:

(12) $$du_t / dS_t^i = -\frac{C_{sg}\omega g^i(G_g - \omega u))}{(\omega C_{ug} g^i - \omega C_u)(G_g - \omega u) + \omega g^i[-(\theta_{gg} g^i + \theta_g)p^d Y\omega - (\rho + \omega u - G_g)C_{ug} + G_{gg} C_u]}.$$

We also need to consider the relationships between the marginal cost of insect control and the insect stock, denoted as $C_{ug}$ and between the marginal cost of storage and the insect stock, denoted as $C_{sg}$. The cost of controlling a given number of insects is more likely to increase as the insect population decreases: $C_{ug} < 0$. As the insect population closely approaches zero, detecting the emergence of minor insect infestations will become more difficult. Also, the cost of storing a given quantity of fruits is more likely to decrease as the insect population decreases: $C_{sg} > 0$.

We distinguish between two cases, $G_g < \omega u_t$ and $G_g > \omega u_t$, to determine the sign of $du_t/dS_t^i$ given these assumptions. The distinction depends on the population dynamics of the insect and the effectiveness of the pesticide. The first case implies that pesticides effectively deter the growth of the insect population, but the second case implies otherwise. We focus on the first case to interpret the result, considering that many modern chemical pesticides used in crop production exhibit a high degree of efficacy and that apple maggot is currently under control. The sign of $du_t/dS_t^i$ is positive unless $G_{gg} < 0$ and the absolute values of $\theta_{gg}$ and $G_{gg}$ are sufficiently large to offset the values of the rest of the other components with an opposite sign. Assuming that such a strict condition is hardly met, we thus find that a higher storage cost increases rates of pesticide application.

## 3. Empirical Model

The empirical model represents a producer of ‘Red Delicious’ apples, the largest apple cultivar by volume in Washington State. Nearly one-third of Washington State’s commercial apple crop consists of ‘Red Delicious’, valued at approximately $621 million per year (WSTFA, 2016). This is the most exported variety at 50% of total apple exports as well as one of the varieties exported to China and BC (Canada). We calibrate the model using ‘Red Delicious’ data on yield (40-lb box/acre) and cost data ($/acre) in full production[20] and on the average price between 2009 and 2015 (see Table 1).

Table 1. Annual Yield and Costs in Full Production for Red Delicious, Average 2009-2015

| | Yield [a] (40-lb box/acre) | Production Cost [a] ($/acre) | Fresh Price [b] ($/40-lb) | Processed Price [c] ($/40-lb) |
|---|---|---|---|---|
| Seven-year average | 1,376 | 24,586 | 17.56 | 3.09 |

[a] Galinato and Gallardo (2016), [b] USDA (2016), [c] WSTFA (2016).

Our ‘Red Delicious’ data and apple maggot data overlap only between 2009 and 2015, in which apple maggot data span from 2003 to 2015. Thus, our analysis is based on seven-year production period.

Production costs include those that are not affected by apple-maggot infestation namely orchard establishment, variable costs (e.g., horticultural management, harvest activities, equipment maintenance), and fixed costs such as depreciation and interest to account for the opportunity costs of the investment (Galinato and Gallardo, 2016). We assume that orchards with infestation will yield a percentage of fruit damaged by apple maggot, which would only be suitable for processed juices or animal food (UMN Extension, 2017). Thus, we use processed juice prices for the damaged percentage of the annual yield and fresh ‘Red Delicious’ apple prices for the non-damaged percentage.

[20] The full production year is representative of all the remaining years after establishment years.

WSDA has identified four types of areas based on the apple-maggot threat and quarantine status: 1) apple maggot free areas, 2) non-quarantined but threatened areas, 3) quarantined but non-threatened areas, and 4) quarantined and threatened areas. In areas designated apple maggot free, the insect is neither found nor established. The insect is considered established when it is expected to continue and multiply, but officially being controlled. A non-quarantined but threatened area is one where the insect has been found in traps less than 0.5 miles from a commercial orchard but is not considered established. An area quarantined but non-threatened is where apple maggot is known to be established but has not been found in traps. Lastly, an area quarantined and threatened is where apple maggot is both found and established.

Our goal is to compare two scenarios—when an orchard is infested with apple maggot vs. not—and to analyze how a producer whose orchard is infested reacts to phytosanitary export regulations. Therefore, our analyses focus on apple maggot free areas and quarantined and threatened areas (see Table 1A). Every year, WSDA monitors apple maggot from June to September in thirteen Washington counties by placing traps and reports apple maggot findings in the traps (see Table 2A). Traps are typically located in places with the greatest risk of pest introduction, particularly un-treated trees such as non-commercial host trees, abandoned apple orchards, and roadside host trees. To estimate the number of apple maggots per acre per year, we use the average number of apple maggots caught in quarantine areas (90 insects) and in pest-free areas (30 insects) from 2009 to 2015 as well as orchard acreage information from the two areas considered.

Eight of the top ten export destinations for Washington apple (Canada, Mexico, United Arab Emirates, Taiwan, India, Indonesia, Vietnam, Hong Kong, Saudi Arabia, and Thailand) impose some type of restriction related to apple maggot (exceptions are Saudi Arabia and Hong

Kong). Restrictions include a cold treatment consisting of storage at 1℃ for an additional 40 days, a phytosanitary certificate, and a special working plan. The last two restrictions are imposed regardless of whether apples are grown in an apple maggot free zone. Consequently, we assume that the additional cold storage requirement only represents an additional cost to producers with an orchard in a quarantine zone. Moreover, most destinations requiring cold treatment include other insect pests besides apple maggot. For example, Mexico imposes restrictions for a list of pests beyond apple maggot, and requires producers in Washington, Oregon and Idaho to comply with the "Work Plan for the Exportation of Apples from the United States to Mexico". Such plan includes among other measures, that all apples, coming from all producing areas (e.g., quarantined and pest-free) be held in cold storage at 1℃ for 40 days (Northwest Horticultural Council, 2018). Only China and BC (Canada) impose the cold storage requirement exclusively for apples grown in apple maggot quarantine areas. Therefore, we consider the case when the orchard is located in a quarantine area and apples are to be exported to China and BC as an additional cost due to apple-maggot phytosanitary regulation (Sansford et al., 2016).

*Empirical Formulation*

We specify an empirical formulation of a fruit producer's objective function in equation (1) as follows:

$$\max_{u_t \geq 0} \int_0^T e^{-\rho t} \begin{bmatrix} p_t^h Y_t (1-\gamma)^{g_t^i} + p_t^l Y_t \left(1-(1-\gamma)^{g_t^i}\right) \\ -(c_u u_t + c_m Y_t + C_t + \alpha Y_t S^i | R) \end{bmatrix} dt. \tag{13}$$

The first term in the function (13) measures the discounted revenue a producer obtains from selling 'Red Delicious' fresh and processing for juice apples, where $p_t^h$ is the price for fresh

‘Red Delicious’ apples and $p_t^l$ is the price for processing for juice apples (both expressed in \$/40-lb box). $Y_t$ represents the ‘Red Delicious’ yield measured in 40-lb box /acre at time $t$. The apple-maggot population at period $t$ determines damages on yield $Y_t$ and $\gamma$ denotes the probability that apple fruits are damaged by an individual apple maggot fly. Similar to Fan et al. (2016), we use $\gamma = 0.001$, implying that the probability the fruit is non-infested is $0.999$. The probability that the fruit remains non-infested from the population size of apple maggot $g_t^i$ is $(0.999)^{g_t^i}$, denoted as $\theta(g_t^i)$ in equation (1), so the probability that the fruit is damaged by the population $g_t^i$ is $1 - (0.999)^{g_t^i}$, denoted as $\left(1 - \theta(g_t^i)\right)$ in equation (1). The probability is calculated using the estimated population size of apple maggot with the data on apple maggot findings presented in Table 2A.

The third term in the objective function represents the discounted costs. Costs include pesticide application, monitoring, horticultural management, harvest, and storage cost. The unit costs of applying pesticides and monitoring the pest are denoted as $c_u$ (\$/acre/application) and $c_m$ (\$/40-lb box), respectively. The unit cost of pesticide application is the average cost of the chemicals commonly used to control apple maggot, such as Assail, Imidan, and Provado (Jay Brunner, personal communication, 2016). Note that the unit cost of pesticide application represents the pesticide costs that additionally take place due to the introduction of apple maggots. The costs of other chemical sprays used as a usual practice in orchard activities are included in the common production costs $C_t$ as presented in Table 1.[21] Note that the costs are

[21] The cost of other chemical sprays account for approximately 4.14% of common production costs.

separable because we assume that the producer's optimal input choice of pesticide is made in a two-stage maximization procedure. This implies that production input decisions are made sequentially, so that there is no substitutability in factors of production (Berndt and Christensen, 1973; Antle, 1983). The unit cost of monitoring is exogenously determined by the Washington State Department of Agriculture. Producers pay a monitoring cost of \$0.006/40-lb box to the state government agency for the inspection. The unit storage cost (\$/40-lb box) is denoted as $S^i$ for $i = \{q, n\}$. For the reasons explained above, we consider export destinations BC and China as representing additional costs due to apple maggot, so the parameter $\alpha$ represents the percentage of total yield exported to these destinations (WSTFA, 2016; WSDA, 2017). The unit storage cost is assumed to be \$0.56/40-lb box conditioned on 85% pack-out for the 'Red Delicious' variety (Galinato and Gallardo, 2016).

A producer's chemical application decision could be affected by Maximum Residue Limits (MRLs), which regulate maximum acceptable levels of pesticides in food and agricultural products. However, it is unlikely that a producer's choice of extra chemical applications to control apple maggots is directly constrained by MRL restrictions because a producer's concern about MRLs would be based on total pesticide use. The Northwest Horticultural Council (a non-profit industry organization based in Yakima, WA, that assists producers and packers in the Pacific Northwest on national and international policy issues) reports that MRL violations on Washington apples in major export markets have been rare over the past ten years (2006–2016). In total, there have been three incidents in three destinations: India, Taiwan, and Thailand

(Northwest Horticultural Council, personal communication, 2017).[22] Under this circumstance, the likelihood of changing the optimal decision of the extra chemical applications to control apple maggots is expected to be low. Thus, we consider a discussion on the role of MRL constraints in a producer's decision to be outside the scope of this study.

*Apple-Maggot Dynamics*

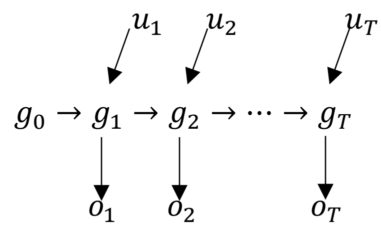
Our functional form for the insect population growth is:

$$g_{t+1}^{i} = \left[g_t^i(1-\omega) + r g_t^i(1-\omega)\left(1-\frac{g_t^i}{\kappa}\right)\right], \quad (14)$$

where $r$ is the intrinsic growth rate, $\kappa$ is the carrying capacity, and $\omega$ is the proportion of the insect killed. The apple-maggot population dynamics given by equation (14) have a classical Schaefer (logistic) functional form measuring the yearly growth of the population in the absence of pesticide applications. We used the growth function based on Fan et al. (2016) on optimal control strategy of spotted wing drosophila (*Drosophila suzukii*), which is in the same order (Diptera) as apple maggot (Ruiz et al., 2007). We take into consideration that insect control action changes the state of infestation and transits to the next period. Thus, the proportion of insects killed $\omega$ is incorporated into equation (14) as a parameter.

[22] In India, a small number of containers of apples were rejected (specific number unknown) in 2014. In Taiwan, five containers were rejected in 2009. In Thailand, fewer than five containers were rejected between 2014 and 2015.

Figure 1. Observation '$o_t$' Generating Process from Population after Pesticide Application




$$o_t | g_t \sim Bionomial\ (g_t, \pi)\text{, where } \pi \text{ is the trapping efficiency, } \ g_0 \sim Uniform$$

The problem of applying population dynamics as defined in equation (14) is that the true apple-maggot population is unknown. In general, insect observation data collected from the traps strategically located in the field (or close by) provide only noisy information about true population dynamics, not the actual population size (Fan et al., 2016). Therefore, we assume that trapping efficiency is uniformly distributed between 0.1% and 1%. This assumption is based on Lance and Gates (1994), who determined the probability of capturing Mediterranean fruit flies in standard trapping arrays (using 10 traps per square mile) and found that the percentage of flies recaptured is approximately 0.6% overall. The number of detections is determined through a binomial sampling—being captured or escaping—from the population, and the maximum number of the detections is set to be less than the population. We estimate the insect population using the Variational Inference method using Python software version 2.7. Lastly, we assume that the intrinsic growth rate $r$ and carrying capacity $\kappa$ follow a uniform distribution (Fan et al., 2016).[23] The parameter values used to calibrate the model are listed in Table 2. Using the

[23] They assume the prior distribution of these two parameters to be uniform.

estimated population size of apple maggot along with the parameter values, we calculate the probability the fruit is damaged by the population $g_t^i$, $1 - (0.999)^{g_t^i}$.

Table 2: Parameter Values for the Empirical Model

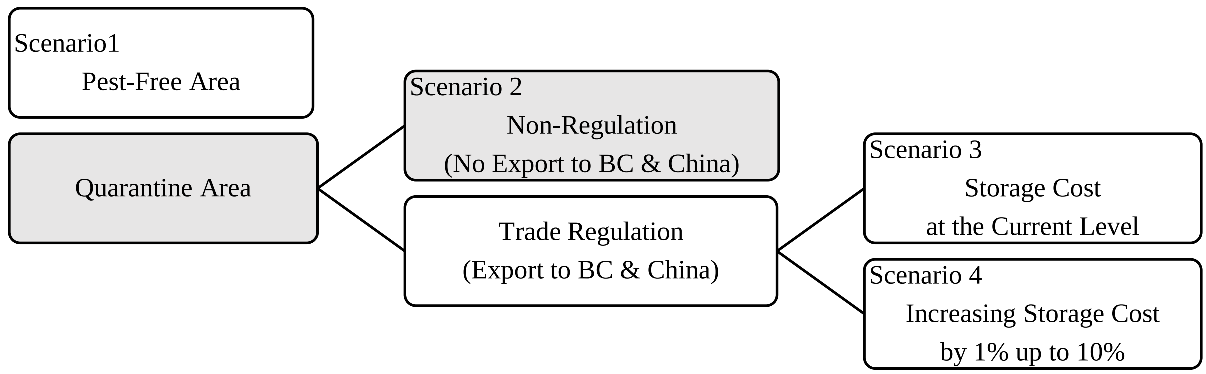
| Notation | Value | Unit | Description |
|---|---|---|---|
| $t$ | 7 | Year | Time period |
| $\gamma$ | 0.001 | | Probability apple fruit damaged by one apple maggot |
| $c_m$ | 0.006 | \$/40-lb | Unit cost of monitoring |
| $\alpha$ | 2 | % | Exports as percent of total yield to China & BC |
| $r$ | *Uniform* (0.01, 20) | Distribution | Intrinsic growth rate |
| $\kappa$ | *Uniform* (100, 10000) | Distribution | Carrying capacity |
| $\omega$ | 0.9 | | Proportion of insect killed |
| $\rho$ | 5 | % | Yearly discount rate |
| $c_u$ | 39.98 | \$/acre/application | Unit cost of applying pesticides [a] |
| $S^q$ | 0.56 | \$/40-lb | Unit storage cost \$11/ 925lb bin [b] |

[a] The unit cost of pesticide application is calculated following Jay Brunner, personal communication, 2015; under the assumption that there exists moderate pressure of codling moth.
[b] The Red Delicious variety is considered an average pack-out of 85%.

## 4. Scenarios, Simulation, and Results

To investigate the change in a producer's economic profits under different levels of pest infestation and existence of phytosanitary trade regulations, we separately estimate a producer's economic profits considering quarantine status: pest-free and quarantine. Next, we estimate the economic impact of the phytosanitary regulation applied to fresh apples shipped from quarantine areas to China and BC (Canada). Finally, we show how the producer's optimal pesticide applications, as well as profits, change as the cost burden for the cold treatment to meet the phytosanitary trade regulation increases. Figure 2 illustrates the four scenarios examined. The first scenario represents an orchard located in a pest-free area, so the phytosanitary trade regulation does not apply. The second scenario describes a producer's orchard located in a quarantine area, but the producer does not export apple fruits to BC and China, so the apple-maggot trade regulation does not apply (shaded in Figure 2). The second scenario is our baseline scenario. In the third scenario, a producer has an orchard in a quarantine area, exports 2% of the orchards total yield to China and BC (Canada), and faces the current level of the cost burden from cold treatment ($11/40-lb box/40 days at 1°C). Lastly, a producer who has an orchard in a quarantine area increases exports to China and BC (Canada), leading to a rise in costs from cold treatment storage of 1% up to 10%. Table 3 presents the simulation results of the four scenarios.

Figure 2. Flow of Scenarios




In the pest-free scenario (scenario1), the seven-year estimated profits for a producer with an orchard in a pest-free area are -$5,339/acre.[24] This profit differs from the production costs outlined in Galinato and Gallardo (2016), who estimated seven-year profits of -$3,792/acre.[25] The main reason for the difference in profits (-$5,339 versus -$3,792 /acre) is that they didn't consider additional spray costs due to the potential apple maggot infestation, leading to unmarketable fresh fruit. Instead, we assume that the chemical spray costs to control apple maggots would change as a producer adjusts spray rates according to the variation of the insect population. Galinato and Gallardo (2016) assume that the chemical costs to control for insects

[24] The profits appear to be negative because the price in the marketing year 2014-2015 was particularly low (less than $14 per 40-lb box), lowering the average price used to estimate the seven-year profits. The average prices in remaining marketing years has been in range between $18 and $19 per 40-lb box.

[25] The estimated seven-year profits in Galinato and Gallardo (2016) are $1,242/acre, using the price ($18.16/40-lb box). The re-estimated profits in their study should decrease from $1,242 to -$3,792 after using a lower average price ($17.56/40-lb box)

are fixed at $199.91/acre. Our results indicate that the optimal annual spray cost amounts to an average of $315.84/acre, reflecting variations in spray application strategies due to insect population dynamics even in a pest-free scenario. [26]

For scenario 2, the estimated seven-year profits for a ‘Red Delicious’ apple orchard operation located in a quarantine area that does not export to BC and China are -$5,737/acre. When an apple-maggot infestation is introduced to an orchard, profits are reduced by $398/acre compared to the pest-free scenario. Considering that the average size of a Washington farm is between 350 and 400 acres (USDA, 2012), the economic loss for an orchard operation could range from $139,300 to $159,200 operation/year.

For scenario 3, the estimated seven-year profits are -$5,992/acre. The trade regulation of invasive species that requires the cold storage period for fresh apples shipped from quarantine areas causes additional economic losses of $185/acre (equivalent to 3%) compared to those estimated in the baseline scenario. Considering that the average size of a Washington farm is between 350 and 400 acres (USDA, 2012), the loss amounts to approximately $65,100 to $74,400 operation/year. The number of necessary sprays increases from eight to nine times per year.

For scenario 4, when the producer faces increasing storage costs, if the unit storage cost increases by 10%, estimated profits decrease to -$7,337/acre. The additional economic loss amounts to $1,600/acre (equivalent to 28%) compared to the profit estimated in the baseline scenario. The empirical relationship between the rate of the pesticide application and the storage

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[26] $315.84 = 7.9 \times 39.98$(= unit spray cost). Recall that apple maggot was found in pest-free areas, but not considered as threated or quarantined

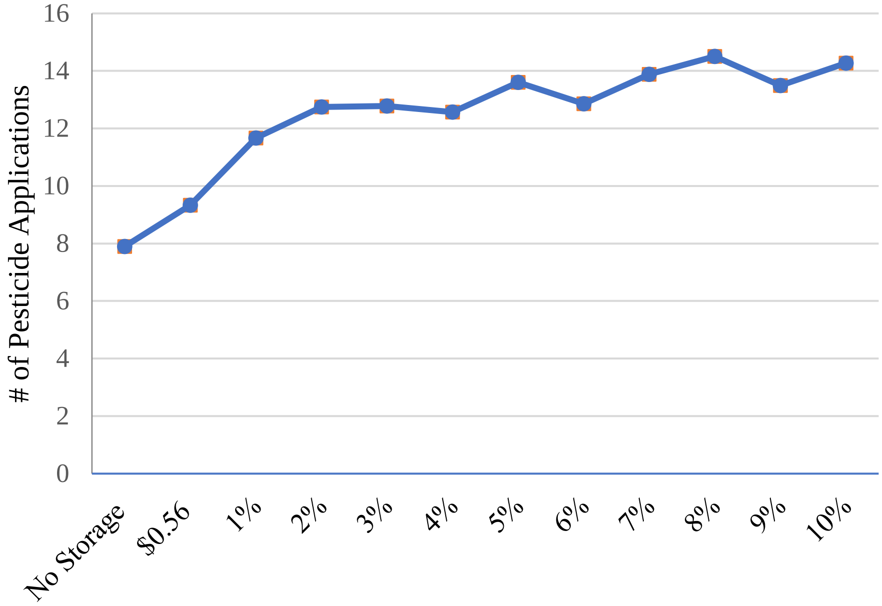
cost is consistent with our theoretical result. We examine the relationship between the two variables by increasing the unit storage cost by 1% up to 10%. We find that the heavier the cost burden for cold treatment, the higher the number of sprays (Figure 3).

Table 3. Results of Empirical Model, Profits and pesticide Applications for Seven Years

| Area | Pest-Free | ------------------------------- Quarantine ------------------------------- | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | 1 | Baseline<br>2 | 3 | 4-1 | 4-2 | 4-3 | 4-4 | 4-5 | 4-6 | 4-7 | 4-8 | 4-9 | 4-10 |
| Storage Cost | 0 | 0 | 0.56 | 0.566 | 0.571 | 0.5768 | 0.582 | 0.588 | 0.594 | 0.599 | 0.605 | 0.610 | 0.616 |
| Increasing Rate of Storage Cost | | | 0% | 1% | 2% | 3% | 4% | 5% | 6% | 7% | 8% | 9% | 10% |
| Seven-Year Profits ($/acre) | -5,339 | -5,737 | -5,922 | -6,616 | -6,885 | -6,962 | -6,942 | -7,089 | -7,011 | -7,021 | -7,339 | -7,047 | -7,337 |
| Optimal Pesticide Applications [a] | 10.99 | 7.90 | 9.34 | 11.66 | 12.75 | 12.79 | 12.57 | 13.60 | 12.86 | 13.89 | 14.51 | 13.50 | 14.27 |

[a] Implies the annual average spray rate.

Figure 3. Relationship between the Storage Cost and the Pesticide Application



*Effect of Delayed Shipment Due to Storage Period*

In addition to storage costs, the mandatory cold storage treatment of fresh apples also decreases a producer's profits. The 40-day delay in shipment potentially causes prices received to be lower. For example, if 'Red Delicious' apples harvested in September in quarantine areas must be shipped in October due to the 40-day storage requirement, the producer would receive the October market price, which is expected to be lower than the September price because early sales by variety are more likely to be sold at a higher price. To examine the effect of delayed shipment due to the required storage period, we use the supply elasticity to calculate expected market prices and profits accordingly. The estimated supply elasticity for 'Red Delicious' is -1.025 (Galinato et al. 2017),[27] indicating that a 1% increase in the supply quantity of total fresh apples leads to a 1.025% decrease in price.

We consider the case in which the supply change is only attributed to the delay in shipments of fresh apples produced in quarantine areas to two export markets: BC and China. By doing so, we can measure how the market price of 'Red Delicious' changes as its export quantity to those two export markets increases. The market price is expected to decrease as the share of yield shipped to BC and China increases. Under the somewhat strict assumption that supply elasticity is constant, we measure how the market price falls according to an increase in dependency on the two markets from 2% (the current level) up to 5%. Table 4 shows that if the share of the 'Red Delicious' apples shipped to BC and China out of total yield rises to 5%, profits will decrease to -$10,618/acre, a difference of $4,881/acre, equivalent to a 85% decline in

[27] Authors' calculation is available upon request.

profits compared to the baseline scenario at -$5,737/acre in which the apple orchard operation is located in a quarantine area but does not export to China and BC (Canada).

Table 4. Effects of the Delayed Shipment on Prices and Profits

| | Current | -------------Projection----------- | | |
|---|---|---|---|---|
| Export to BC & China (% of total yield) | 2% | 3% | 4% | 5% |
| Estimated Price ($/40-lb box) | 17.56 | 17.38 | 17.20 | 17.02 |
| Seven-Year Profits ($/acre) | -5,922 | -8,986 | -9,289 | -10,618 |

## 5. Summary and Conclusion

This study examines the effect of trade regulation of invasive species on a producer's optimal control and evaluates its economic consequences. We theoretically model how a producer adjusts his or her pesticide application when faced with different circumstances with respect to the intensity of infestation and the existence of a phytosanitary trade regulation. Our model predicts that a higher cost burden associated with complying with the regulation increases the rate of pesticide applications.

Using seven years of data on 'Red Delicious' and the number of trapped apple maggots in Washington, we simulate the model under four scenarios varying by the orchard quarantine status (pest-free, quarantine) and the existence of the phytosanitary regulations requiring an additional period cold storage. Our empirical simulation results are consistent with our theoretical results in that an increasing cost burden for the cold treatment, required to export fresh apples from quarantine areas to BC and China, raises the number of chemical applications, suggesting a substitution effect between pesticide application and cold storage. If a producer has an orchard within quarantine areas and exports 2% of total yield to BC and China, he or she will encounter a profit loss of approximately $186/acre compared to producers not exporting to these two markets. For a producer with an average-sized farm between 350 and 400 acres, the loss amounts to approximately $65,100–$74,400/operation. Furthermore, we account for the possibility that late shipment due to the phytosanitary regulation could cause the market price of fresh apples harvested relatively early to fall. We found that if the share of the output shipped to the two markets rises to 5%, profits decrease by $4,881/acre (85%) compared to the baseline case of not exporting to the two markets.

Considering the increasing dependency of the industry on export markets, findings in this study could be useful in preventing apple-maggot expansion in Washington State. This study demonstrates how economic profits of a representative orchard operation could be negatively affected if apple maggot spreads and establishes in the core of commercial apple production in Washington State. Given the importance of the apple industry to the state's economy, these findings suggest that the risk of apple-maggot infestation should be kept at minimum levels by preventing any practice that would increase this risk. It also shows the economic impact of the phytosanitary regulations. In a scenario where the U.S. apple industry is becoming more dependent on export markets, negotiating phytosanitary regulations is key to guarantee the economic profitability of the apple operations.

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**Appendix**

Appendix: Total Derivation and Cramer's Rule for Comparative Statistics

Taking the total derivative with respect to $S_t^i$ for each of equations (10) and (11) yields

(A1) $\omega C_{gu} {du}/{ds}\, g^i + \omega C_{gg} {dg^i}/{ds}\, g^i + \omega C_{gs} g^i - p^d Y \omega \theta_{gg} {dg^i}/{ds}\, g^i - p^d Y \omega \theta_g {dg^i}/{ds} - \rho C_{uu} {du}/{ds} - \rho C_{ug} {dg^i}/{ds} - \rho C_{us} - \omega C_u {du}/{ds} - \omega u C_{uu} {du}/{ds} - \omega u C_{ug} {dg^i}/{ds} - \omega u C_{us} + G_{gg} {dg^i}/{ds}\, C_u + G_g C_{uu} {du}/{ds} + G_g C_{ug} {dg^i}/{ds} + G_g C_{us} = 0.$

(A2) $G_g {dg^i}/{ds} - \omega g^i {du}/{ds} - \omega u {dg^i}/{ds} = 0.$

The matrix format is

$$\begin{bmatrix} \omega C_{gg} g^i - p^d Y \omega \theta_{gg} g^i - p^d Y \omega \theta_g - \rho C_{ug} - \omega u C_{ug} + G_{gg} C_u + G_g C_{ug} & \omega C_{gu} g^i - \rho C_{uu} - \omega C_u - \omega u C_{uu} + G_g C_{uu} \\ G_g - \omega u & -\omega g^i \end{bmatrix} \begin{bmatrix} {dg^i}/{ds} \\ {du}/{ds} \end{bmatrix} =$$

$$\begin{bmatrix} -\omega C_{gs} g^i + \rho C_{us} - G_g C_{us} + \omega u C_{us} \\ 0 \end{bmatrix}.$$

By Cramer's rule, we see that

(A3)

$$
{du_t}\Big/{dS_t^i} = -\frac{\begin{vmatrix} \omega C_{gg} g^i - p^d Y \omega \theta_{gg} g^i - p^d Y \omega \theta_g - \rho C_{ug} - \omega u C_{ug} + G_{gg} C_u + G_g C_{ug} & -\omega C_{gs} g^i + \rho C_{us} - G_g C_{us} + \omega u C_{us} \\ G_{gg} - \omega u & 0 \end{vmatrix}}{\begin{vmatrix} \omega C_{gg} g^i - p^d Y \omega \theta_{gg} g^i - p^d Y \omega \theta_g - \rho C_{ug} - \omega u C_{ug} + G_{gg} C_u + G_g C_{ug} & \omega C_{gu} g^i - \rho C_{uu} - \omega C_u - \omega u C_{uu} + G_g C_{uu} \\ G_g - \omega u & -\omega g^i \end{vmatrix}}.
$$

The comparative statics between $S_t^i$ and $u_t$ at the steady state is driven as follows:

(A4)

$$
{du_t}\Big/{dS_t^i} = -\frac{\left[C_{gs}\omega g^i - (\rho + \omega u - G_g) C_{us}\right](G_g - \omega u)}{\left[\omega C_{gu} g^i - (\rho + \omega u - G_g) C_{uu} - \omega C_u\right](G_g - \omega u) + \omega g^i \left[\omega C_{gg} g^i - (\theta_{gg} g^i + \theta_g) p^d Y \omega - (\rho + \omega u - G_g) C_{ug} + G_{gg} C_u\right]}.
$$

Table 1A. Apple Orchard Acreage by Threat and Quarantine Status due to Apple Maggot

| Threat status of orchards | Quarantine status | Conventional apple orchards | |
|---|---|---|---|
| | | Acres | % of total |
| AM Threatened | Quarantine | 1,351 | 0.83% |
| AM Threatened | Non-quarantine | 184 | 0.11% |
| Non-threatened | Quarantine | 23,224 | 14.21% |
| Non-threatened | Non-quarantine | 138,683 | 84.85% |
| Total | | 163,442 | 100% |

Source: WSDA NRAS, WSDA Pest Program (personal communication, 2016).

Table 2A. Insect-Vector Stocks per Unit Area

| Year | Total | Quarantine | Pest-free |
|---|---|---|---|
| 2015 | 283 | 220 | 63 |
| 2014 | 131 | 95 | 36 |
| 2013 | 78 | 25 | 53 |
| 2012 | 67 | 51 | 16 |
| 2011 | 58 | 35 | 23 |
| 2010 | 103 | 91 | 12 |
| 2009 | 123 | 115 | 8 |
| 2008 | 300 | 284 | 16 |
| 2007 | 287 | 266 | 21 |
| 2006 | 232 | 226 | 6 |
| 2005 | 872 | 845 | 27 |
| 2004 | 171 | 136 | 35 |
| 2003 | 60 | 60 | 0 |

Figure 1A. Number of Apple Maggots Caught